

NEW

Everything you want to know about the world we live in

HOW IT WORKS

Annual

1000s
OF AMAZING
FACTS
INSIDE

Digital
Edition

FUTURE
VOLUME 10

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

WELCOME TO HOW IT WORKS Annual

Welcome to the tenth volume of the How It Works Annual, where your burning questions about how the world ticks finally get answered. Feed your mind, indulge your curiosity and uncover the truth behind some of the most popular misconceptions. We delve deep into the mysteries of our world with in-depth and entertaining articles, accompanied by cutaways, illustrations and incredible images to show you exactly what goes on inside. The How It Works Annual explores the universe through six areas of knowledge: technology, transport, the environment, history, science and space. Our subjects range from the dinosaurs and meteor showers to the future of technology and the greatest engineering feats of the modern world. In this edition, you'll also find a special feature on humankind's efforts to recreate the Sun's immense power on Earth. We've also got features on the devastating Chernobyl disaster, the robots who will soon play a key role in warfare and the gigantic new sewer system currently being excavated below the busy streets of London.

Ready to learn more about the astounding world around you?
Then read on and be amazed.



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F U T U R E
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HOW IT WORKS Annual

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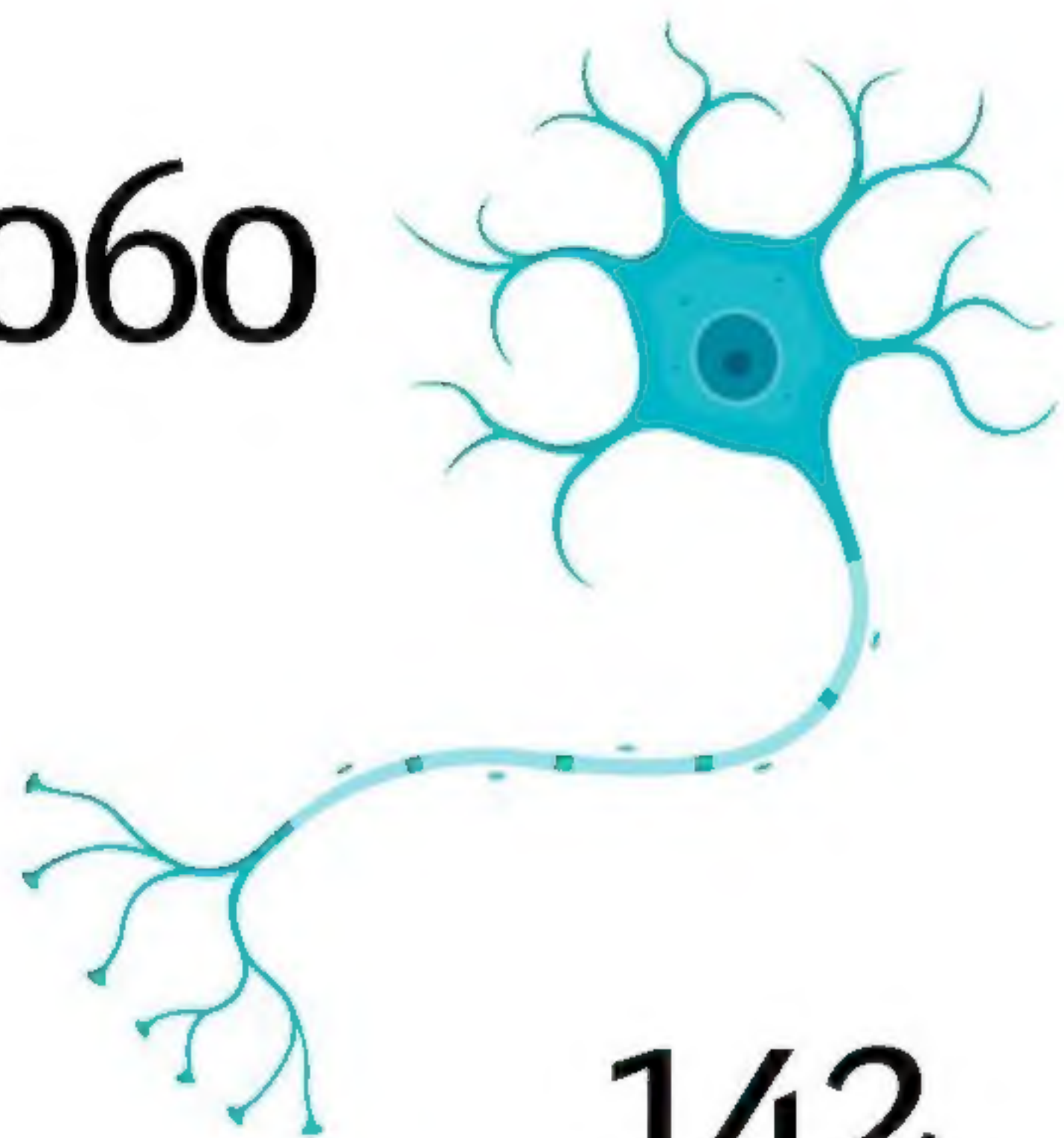


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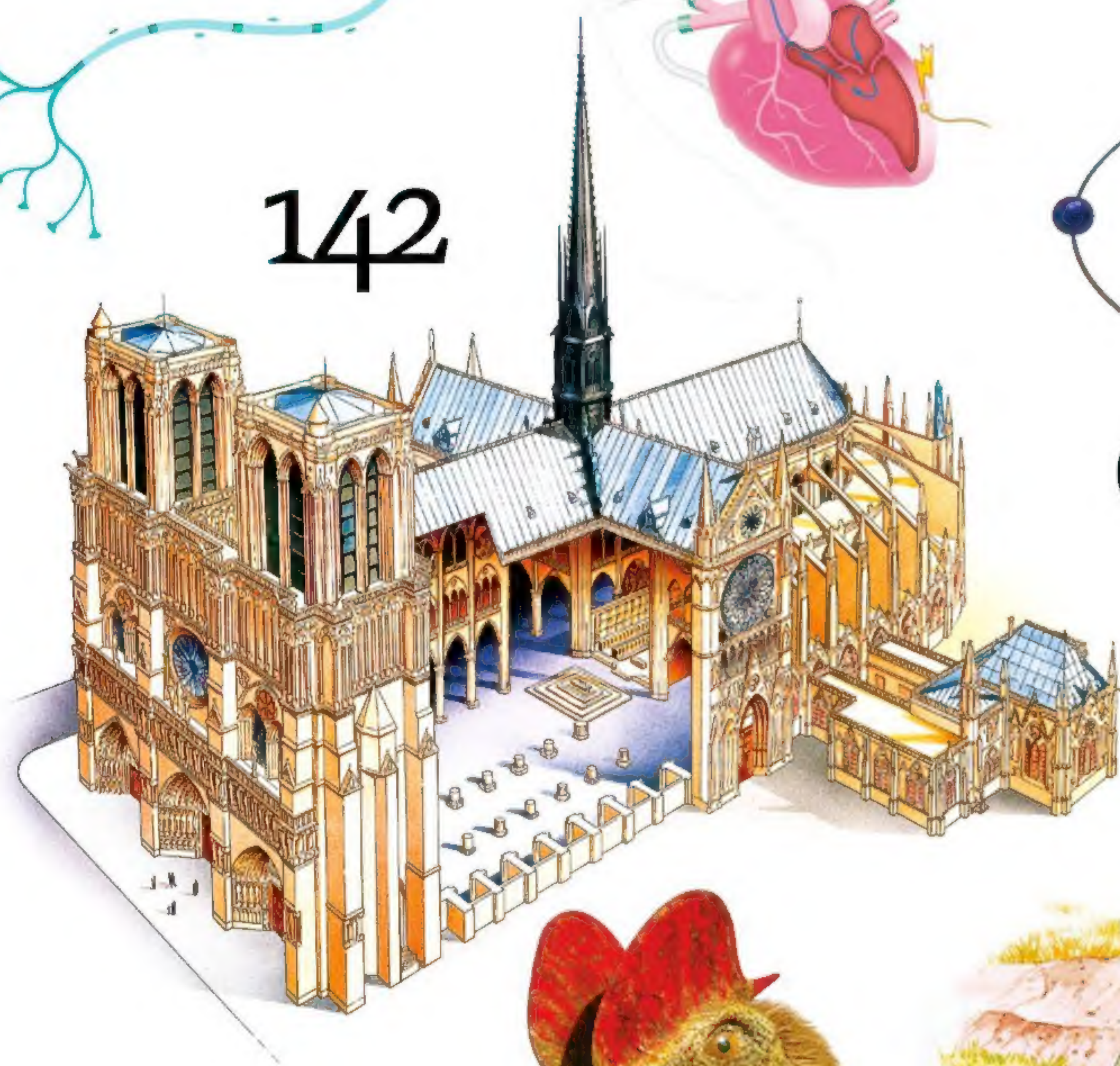
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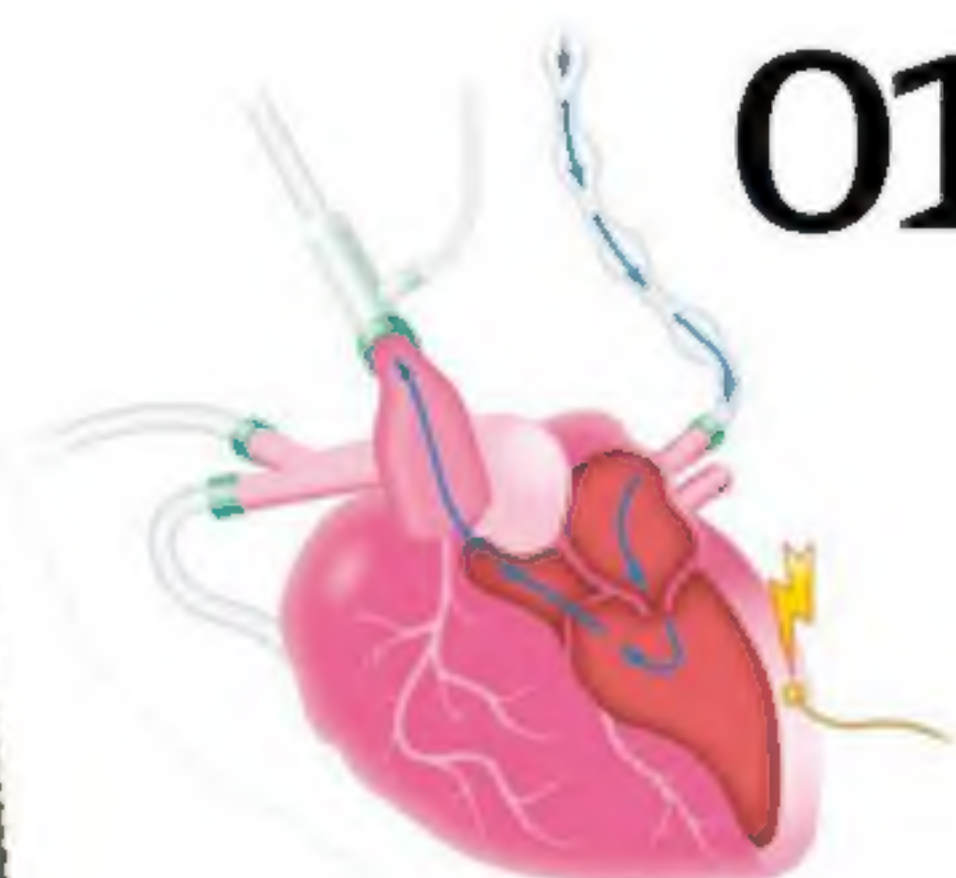
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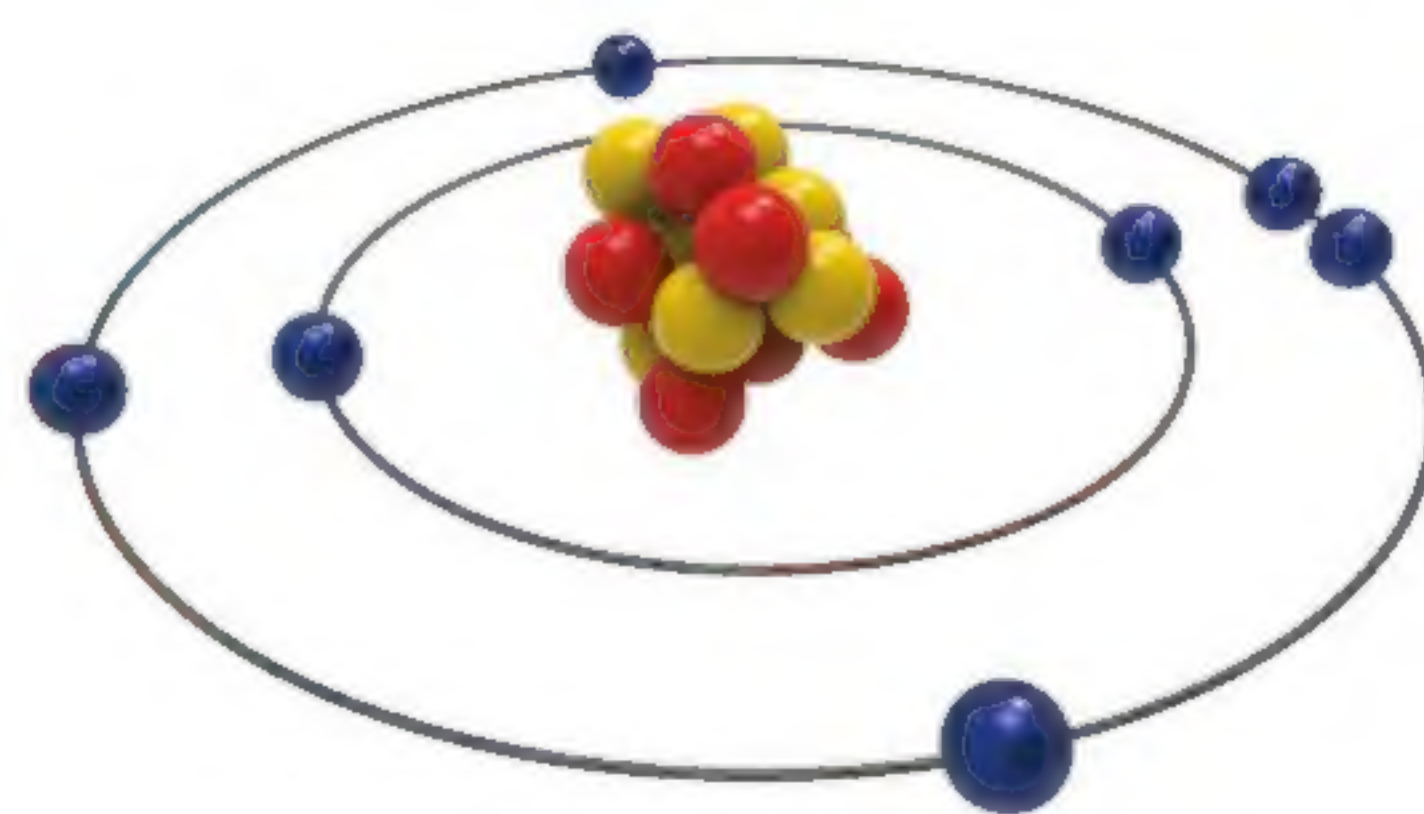
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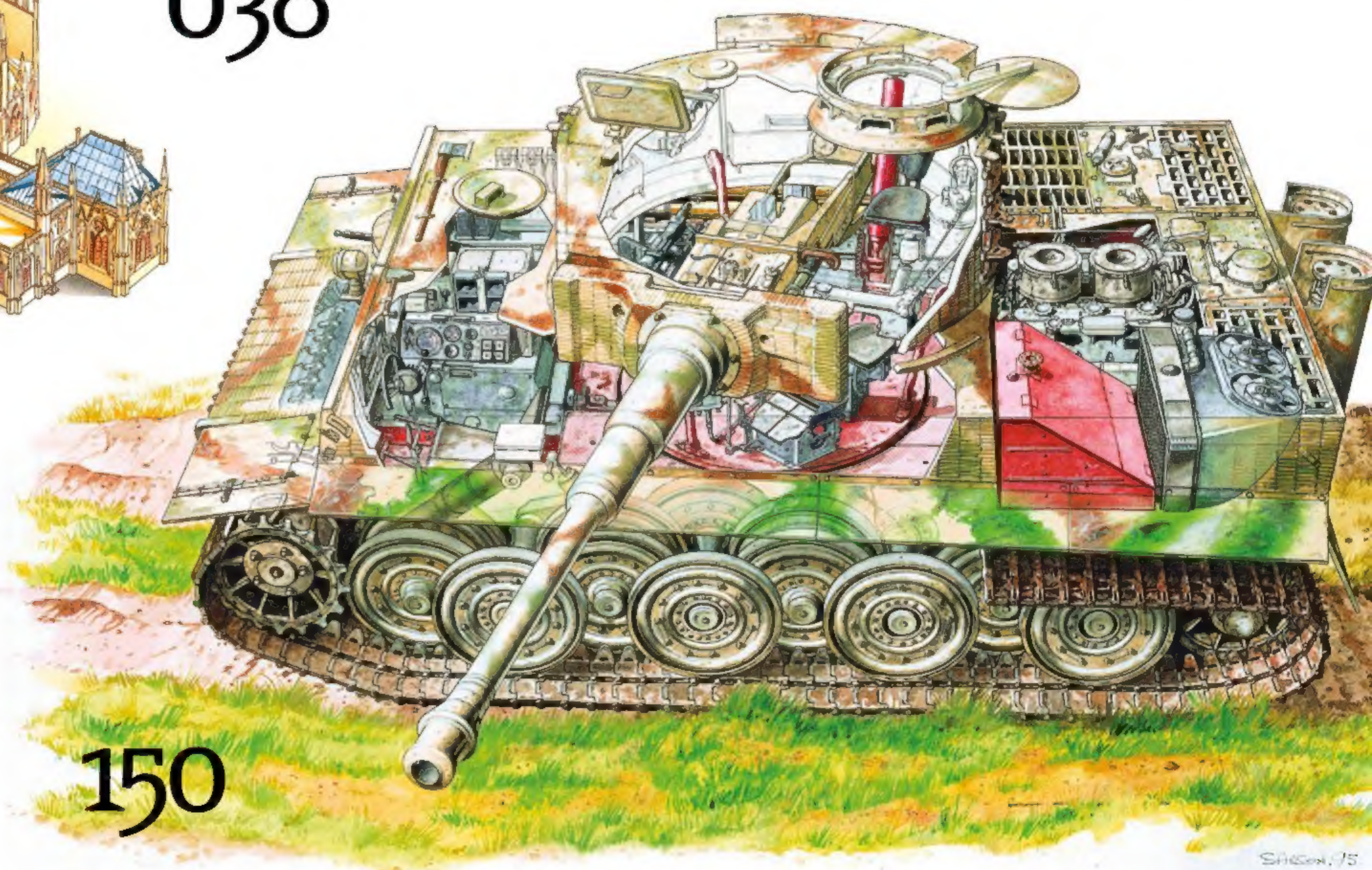
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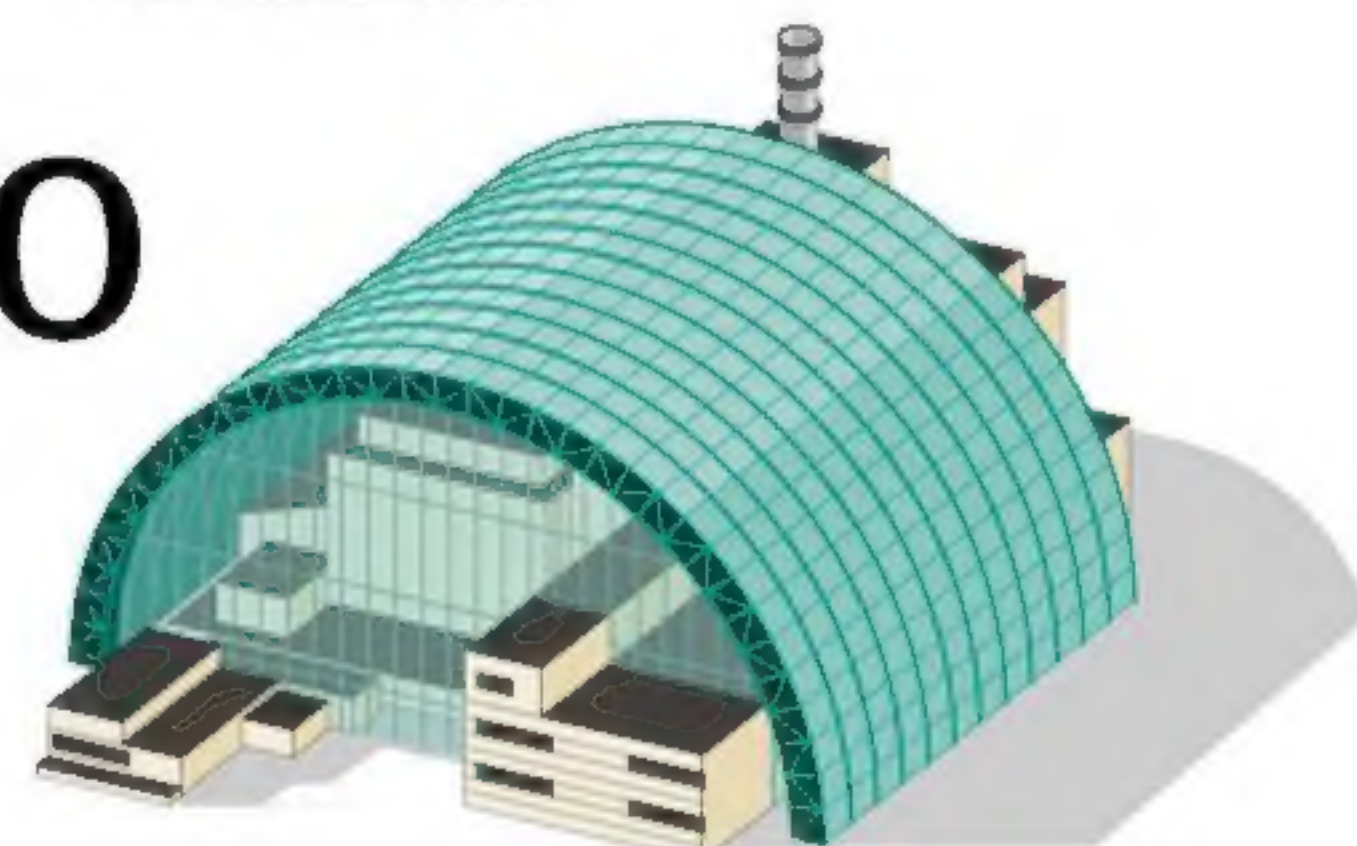
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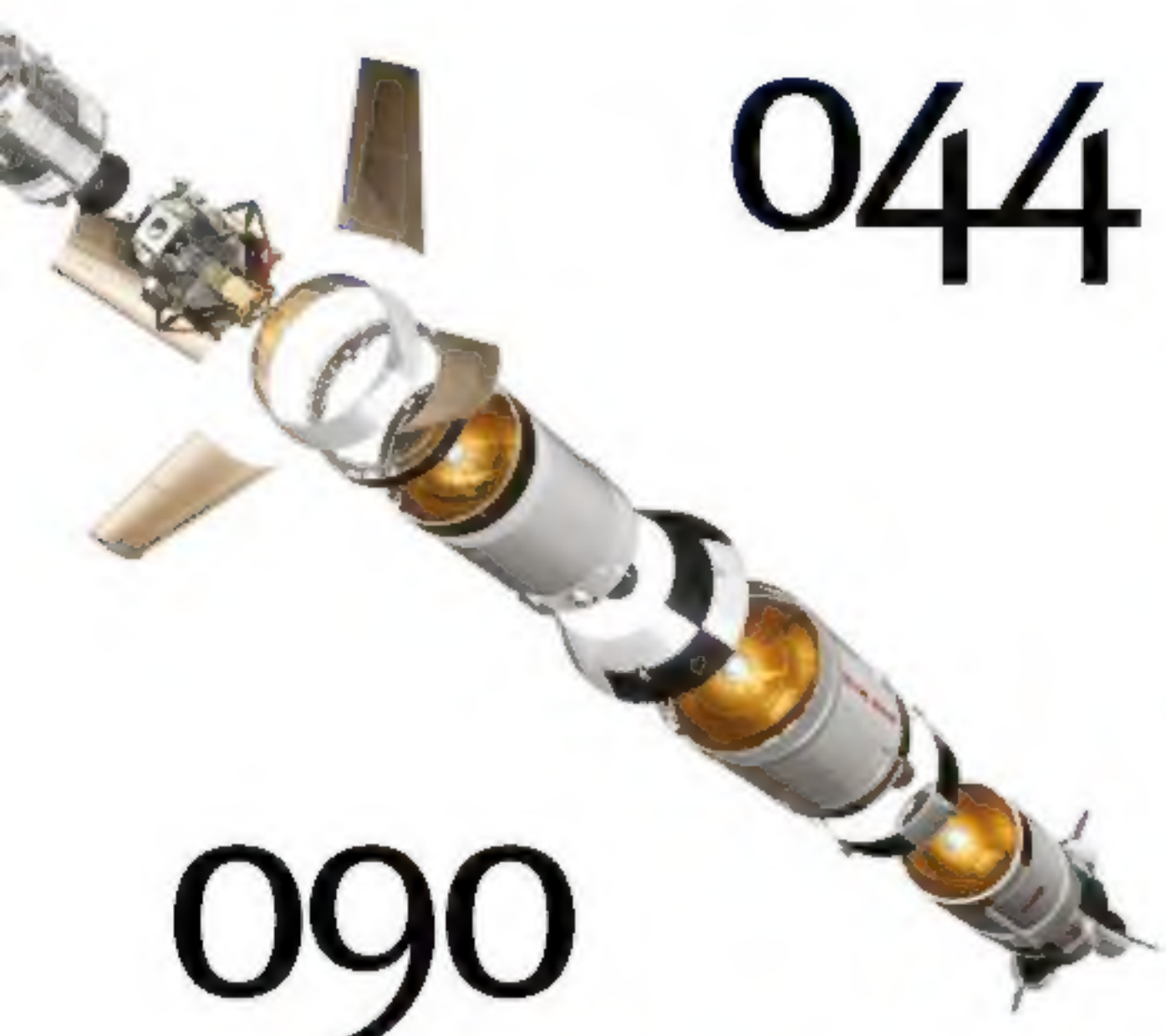
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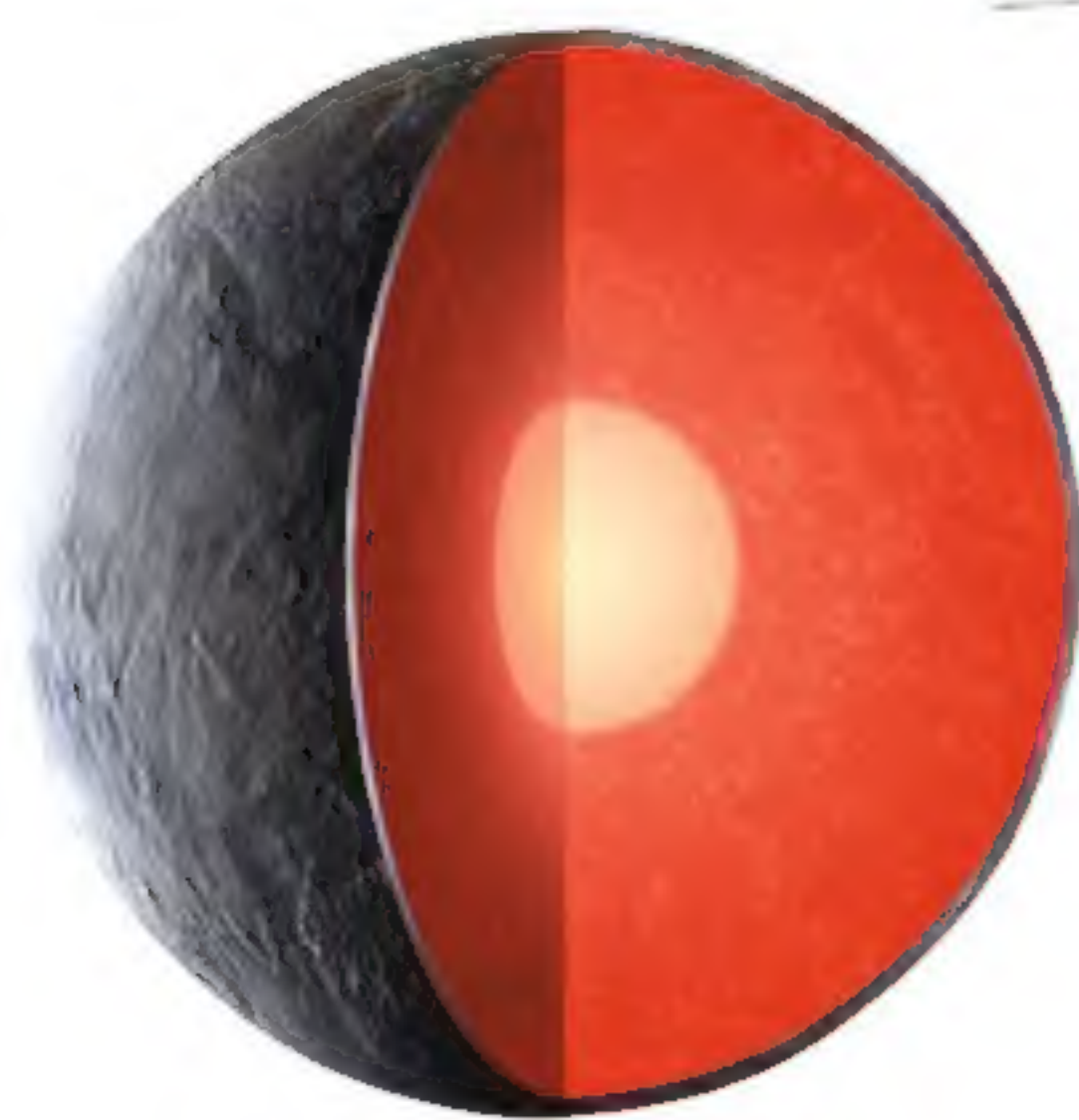
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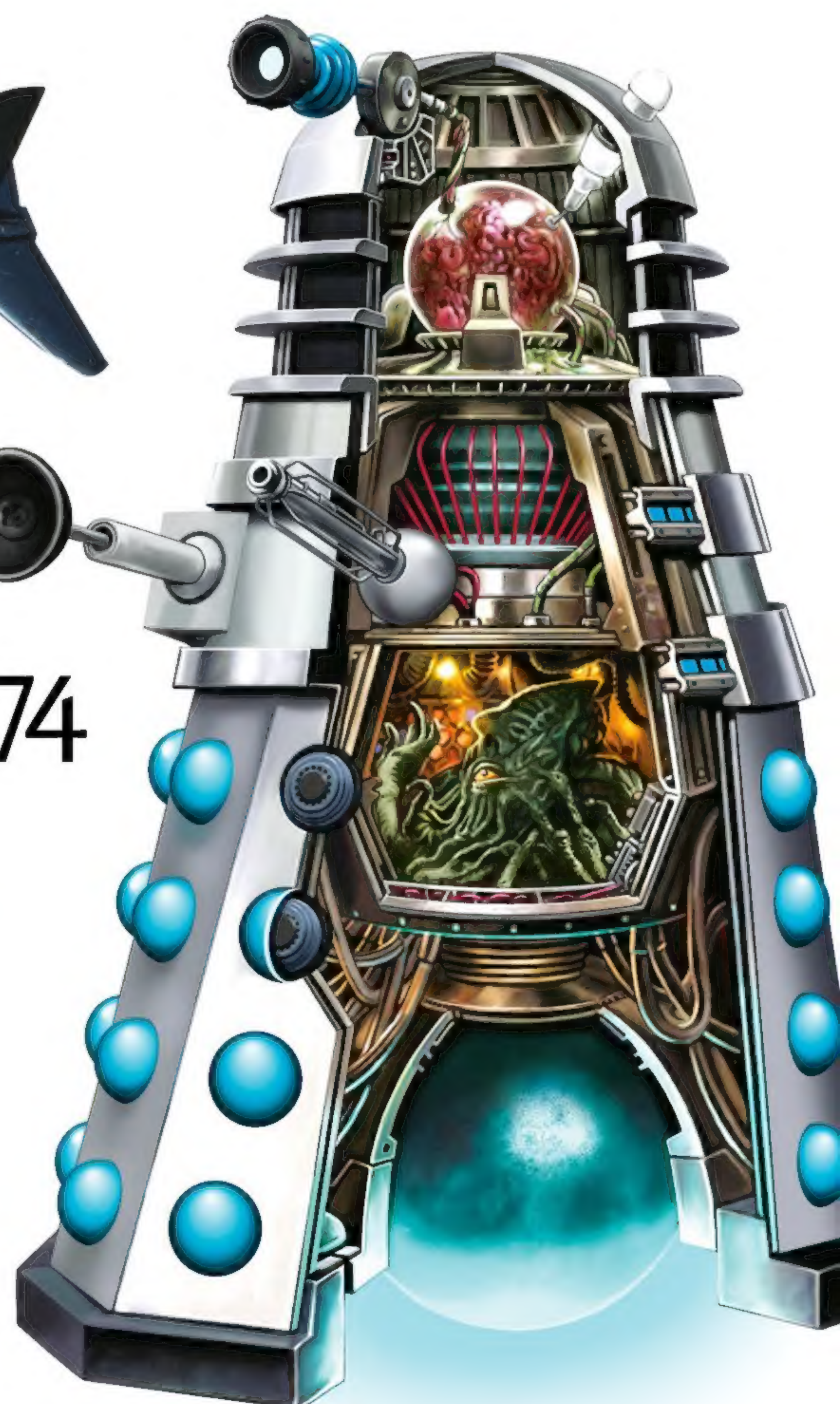


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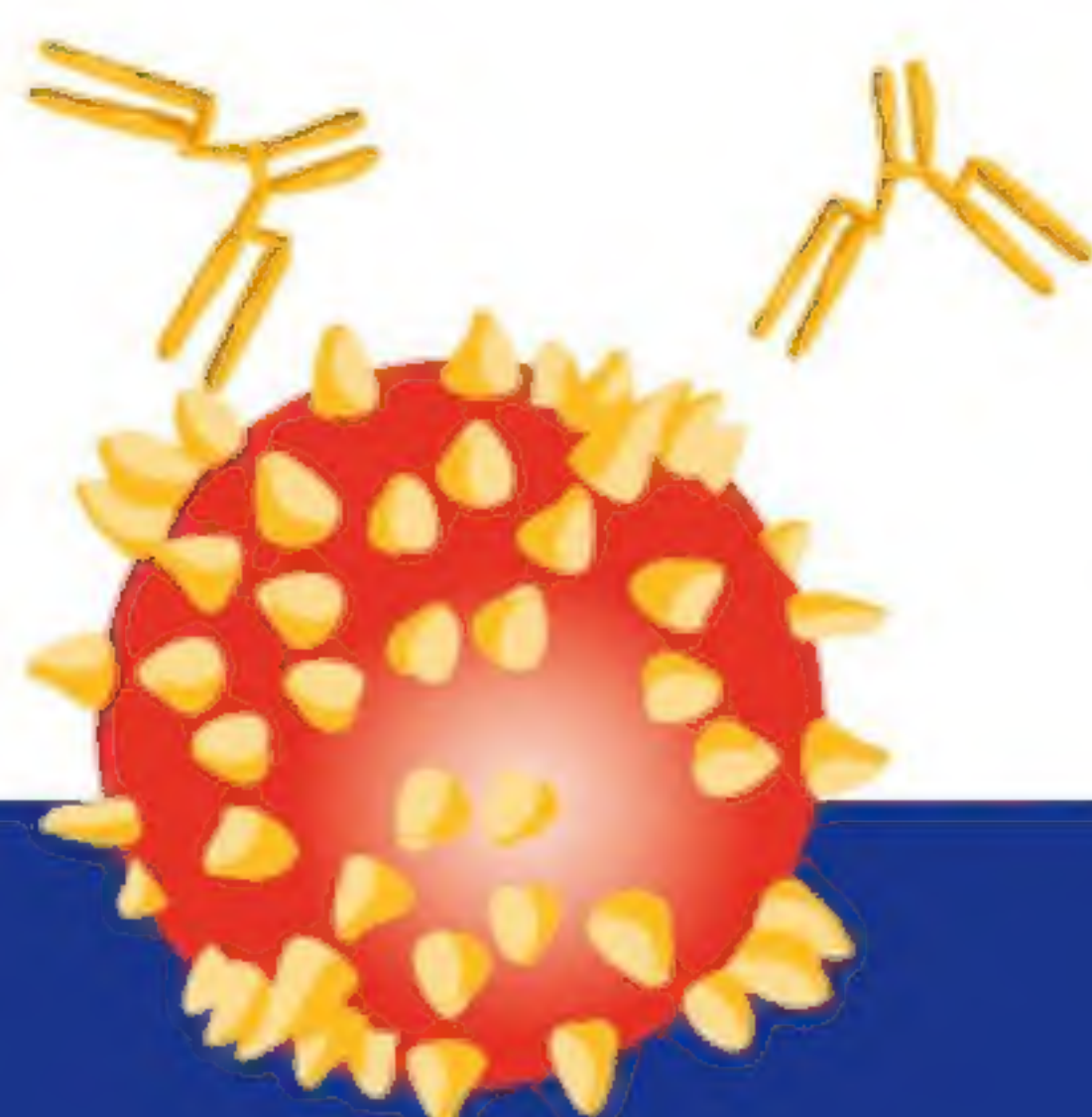
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POWER OF THE SUN

Our star is the heartbeat that keeps Earth alive. Can we recreate this fundamental energy source on Earth?

Words by **Laura Mears**

The Sun is the powerhouse of the Solar System, and this giant fusion reactor is vital to life on Earth. Almost every organism on the planet owes its life to our nearest star. Its stellar pulse depends upon the smallest and lightest element in the universe – hydrogen – and a reaction called the proton-proton chain.

Hydrogen atoms are as simple as they come. The basic version has one positively charged proton for a nucleus, orbited by one negatively charged electron. Normally, atoms keep their distance from one another; the positive charges inside their nuclei repel, like magnets. But at the heart of the Sun, the temperature and pressure is intense. The atoms there move so quickly that they slam through the repulsive nuclear forces, colliding at high speed. When these collisions happen, the nuclei can get stuck together.

Nuclear fusion takes place in stages, starting with a collision between two

protons. When this collision happens, one proton spits out a positron (a positively charged electron) and a neutrino (an electron with no charge). With these two particles missing, one proton becomes a neutron, and the pair form a heavier isotope of hydrogen called deuterium.

The next stage happens when that deuterium hits another proton. This fusion releases a burst of gamma radiation and creates a new type of atom – a light version of helium called helium-3. Now carrying two protons and one neutron, this atom is ready for the final stage of the fusion process.

When two helium-3 atoms collide, they fuse to make an alpha particle (helium-4). This particle contains two protons and two neutrons (like a normal helium nucleus). The remaining two protons shoot away, ready to go through the cycle again.

But how does this create energy? To understand the power of the Sun, we need to

delve into the equations of one of the greatest scientists who ever lived: Albert Einstein. In his theory of special relativity, Einstein explained that mass and energy are the same, and one can become the other. His famous equation, $E = mc^2$, describes their relationship. The energy (E) of an object is equal to its mass (m) multiplied by the square of the speed of light (c). This is the relationship that powers the nuclear reactor at the heart of our star.

The helium nuclei the Sun produces have less mass than the hydrogen nuclei that made them. When the atoms slam together, a tiny proportion of their mass (less than one per cent) escapes. Less than one per cent might sound tiny, but a quick look back at Einstein's equation explains how nuclear fusion produces so much power. The speed of light is 299,792,458 metres per second, so it only takes a tiny release of mass to let out a huge amount of energy.

The Sun has been converting mass into energy for more than 4 billion years, and it's already burnt through a lot of fuel. If you looked into the core today, you'd find that around 62 per cent of the hydrogen nuclei have already fused to become helium. However, there's a lot of hydrogen left and the process happens slowly, which is lucky for us, because almost all life on Earth depends upon the Sun for survival.

Though we don't yet know exactly how life evolved, we know that the Sun played an important role. Before life, Earth had no oxygen in its atmosphere. The air was a thick fog of carbon dioxide, methane and sulphurous gases venting out from the molten rocks. Life emerged around 3.8 billion years ago, probably in hot vents deep under the sea.

"The Sun has been converting mass into energy for more than 4 billion years"

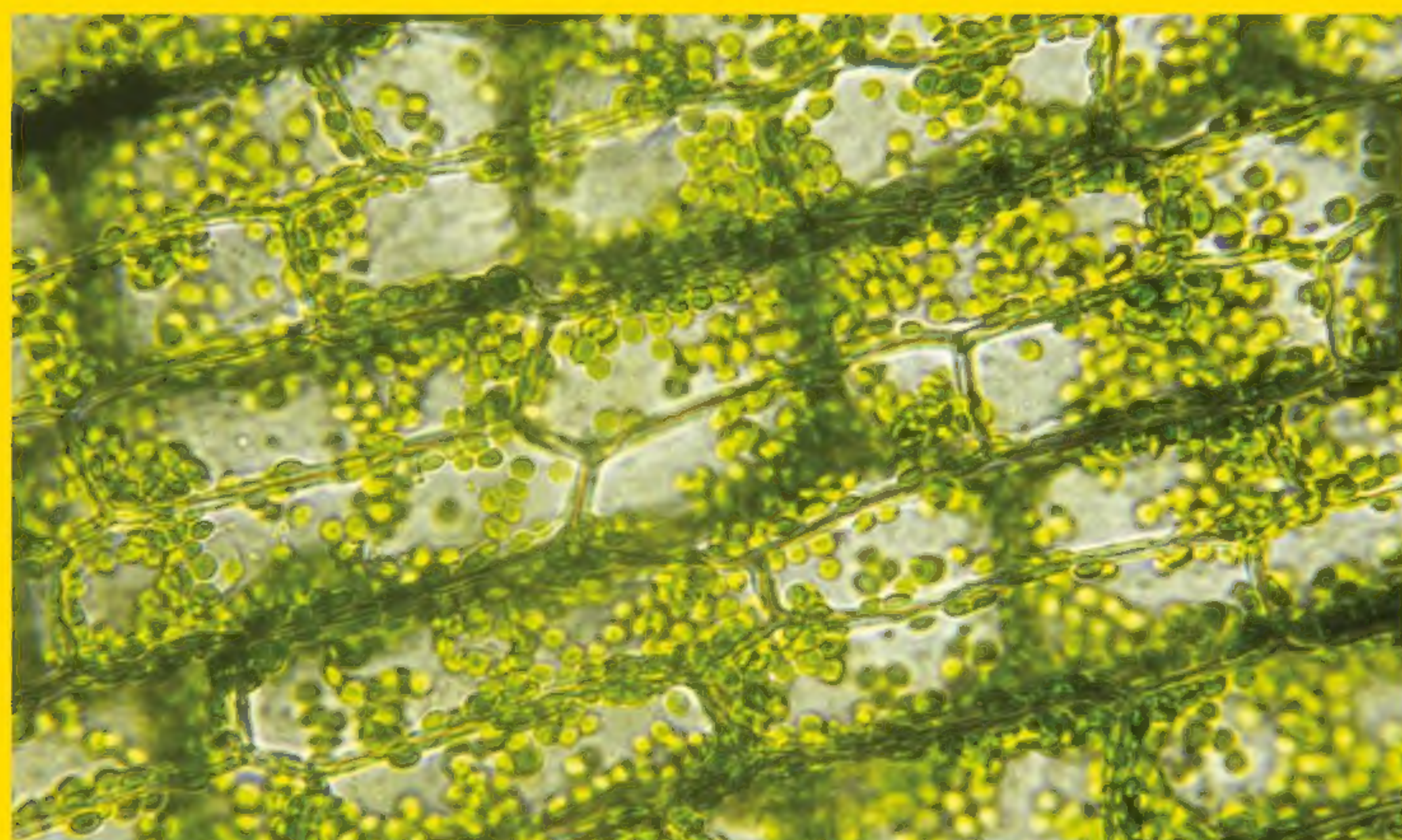
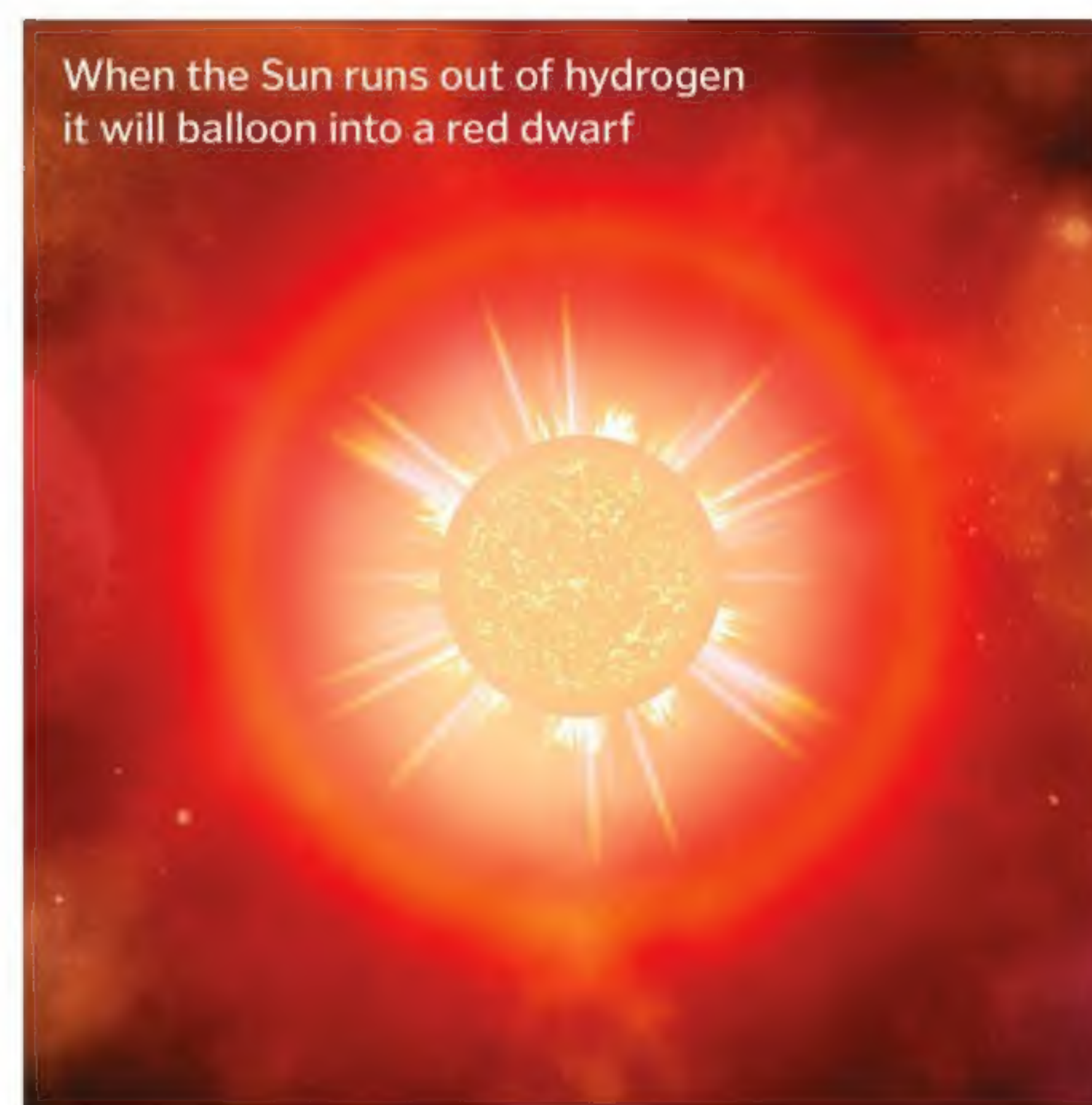
The hydrogen bomb 'Ivy Mike' triggered nuclear fusion on Earth for the first time



A few types of modern microbe still live in these strange environments, including bacteria called acetogens and archaea called methanogens. They harvest chemicals from Earth's rocks, strip electrons away and use the energy to break the oxygen out of carbon dioxide.

This enables them to make organic molecules like acetate and methane, and energy-carrier molecules like ATP. The trouble with these reactions is that they don't make that much energy. For life to boom on Earth, organisms needed a better way to power their

When the Sun runs out of hydrogen it will balloon into a red dwarf



The tiny green chloroplasts that power these cells used to be free-living bacteria

Converting sunlight into food

Plants trap the Sun's power in two high-energy molecules, NADPH and ATP, before releasing it again to make sugar and oxygen. The process begins with two lower-energy molecules, NADP⁺ and ADP, and two types of chlorophyll, P680 and P700.

The chlorophylls work together with other pigments to capture photons of light. P680 goes first, absorbing a photon and spitting out an electron. The electron passes into a transport chain, releasing energy as it moves from link to link. This energy powers the production of ATP.

At the end of the chain, the electrons reach P700, which absorbs its own photon and passes the electrons into a second transport chain. This time, they power the production of NADPH.

The NADPH and ATP molecules go on to power a series of chemical reactions called the Calvin cycle. The cycle combines carbon dioxide with hydrogen ions to make sugar, providing the building blocks that keep life on Earth alive.

HOW THE SUN CREATES ENERGY

Inside the Sun's nuclear reactor is a massive matter-to-energy converter

The radiative zone

Radiation ricochets around in the interior of the Sun for over 170,000 years before it finds its way out.

Thermonuclear fusion

Hydrogen atoms in the Sun's core fuse together, forming helium and releasing pulses of gamma radiation.

The convection zone

Radiation heats a layer of ionised atoms, forming a swirling pool of bubbling plasma.

Collisions

Ions in the hot plasma slam together, releasing energy as photons of light.

The core

The temperature at the heart of the Sun is 15 million degrees Celsius.

Gamma radiation

The energy released by thermonuclear fusion travels outward through the radiative zone.

The chromosphere

The red-tinged inner atmosphere of the Sun contains luminous fingers of gas bursting up from below.

The photosphere

The Sun emits a stream of energy as electromagnetic radiation (heat and light) and charged particles (solar wind).

The corona

Excess heat in the white halo around the Sun boosts the speed of charged particles, spitting them into space.

A STAR IS BORN

The experimental tokamak power plant uses magnets, vacuums and hot plasma to fuse atoms and create a synthetic Sun

Magnetic field

When the central magnet switches on, it induces a powerful magnetic field in the plasma ring.

Insulation

A steel shell encases the system in a vacuum, keeping the temperature cool.

Doughnut magnets

Toroidal field coils keep the plasma under control by forcing it into a doughnut shape.

Plasma protection

Ring-shaped magnets keep the plasma away from the walls of the vacuum vessel.

Divertor

The waste-disposal system sits under the vacuum chamber, removing heat and ash.

Magnetic cage

A constant current through the toroidal magnets creates a doughnut-shaped magnetic field.

Blanket modules

These shields coat the inner surface of the vacuum vessel, protecting the magnets from the products of fusion reactions – heat and stray neutrons.

Particle cannon

The ion cyclotron system accelerates beams of particles and fires them at the plasma, heating it up.

Vacuum vessel

This sealed, air-free chamber contains the ring of plasma.

CREATING CURRENTS

A ring of super-hot plasma swirls at the heart of the tokamak

Plasma

In this high-energy state of matter, electrons break away from atoms, creating a soup of charged particles.

Containment

The magnetic field interacts with the charged particles in the plasma, trapping them inside the ring.

Transient fields

Pulses from the poloidal magnets induce a current in the plasma, creating magnetic fields that pass around the doughnut.

Stirring the soup

The fields from the toroidal magnets interact with the fields from the poloidal magnets, twisting the plasma current.

chemistry. Enter the phototrophs. These organisms use the energy from light to break into chemical bonds.

The most famous phototrophs are, of course, plants. Plant cells contain dozens of chloroplasts, each stuffed with discs called thylakoids. The thylakoids house molecular machines called photosystems, which contain chlorophyll pigments. These capture photons of light from the Sun, harnessing their energy.

Evolving the ability to make chlorophyll is so complicated that scientists think it happened only once. This means that every organism that uses chlorophyll must have come from the same ancestor – photosynthetic cyanobacteria that lived more than 2.15 billion years ago. These strange cells were able to make food and oxygen from light, and other cells wanted to get in on the action. Larger cells started to live alongside the bacteria, sharing their resources. The relationship became so close that the larger cells eventually absorbed the smaller ones. The two types of cell evolved together, and the bacteria lost the ability to live on their own, becoming the chloroplasts we see in plant cells today. Photosynthesis now provides the raw materials for almost every food web on the planet.

Sun-powered evolution changed Earth, but while we've been busy adapting to sunlight, the

Sun has been changing too. It's been fusing hydrogen for 4.5 billion years, and in that time it's been getting brighter. For every four hydrogen atoms that it fuses to make a helium nucleus, the mass inside its core drops. There are now far fewer atoms in the centre of the star, and this means that there are fewer particles to balance gravity pulling inwards and the gas pressure pushing outward.

This causes the Sun's core to contract, which causes the remaining particles to heat up, and in turn speed up nuclear reactions and make the Sun brighter. As this happens, the gas around the outside of the Sun expands. Over the last 4 billion years it has become around 20 per cent bigger, and it is still growing.

On shorter timescales, the power output of the Sun has been fluctuating too. Its atmosphere is stormy, and magnetic activity below the surface creates solar weather in the form of sunspots. They start out near the Sun's poles and move towards the equator, growing to planet-sized magnetic swirls. In the early 1800s, William Herschel noticed that when the number of sunspots dropped, the price of wheat rose. The weather on the surface of the Sun coincided with a period of drought on Earth; it seemed to affect the weather here. People started to track sunspots and noticed cyclical patterns: every 11

Countdown to fusion power

Can TAE Technologies plug a fusion powerplant into the grid by 2023?

1998

Development and testing of the science begins, leading to more than 800 patents

2009

Construction of a full-scale machine is completed and equipment testing begins

2013

The system is upgraded with a powerful plasma injector, built by the Budker Institute of Nuclear Physics, Russia

2015

The temperature in the reactor reaches 10 million degrees Celsius – for full fusion, it needs to reach 3 billion degrees Celsius

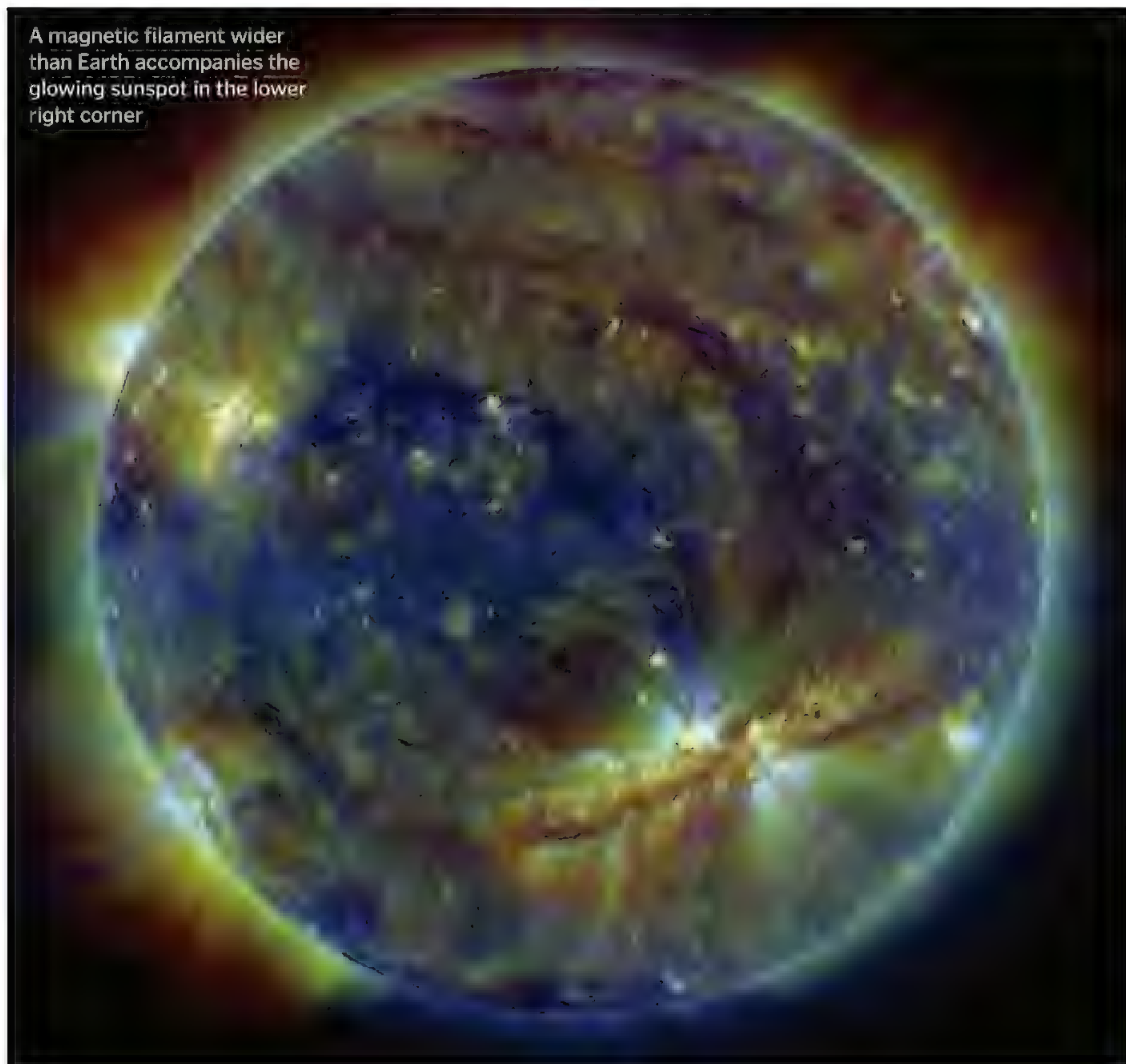
2018

After 4,000 experiments, the system nearly reaches 20 million degrees Celsius

2023

The target temperature will be reached, the technology will be licensed and construction of fusion power plants will begin

A magnetic filament wider than Earth accompanies the glowing sunspot in the lower right corner



"Photosynthesis provides the raw materials for almost every food web on the planet"

years, the number of sunspots rises and then falls again.

We still don't know why this solar cycle is 11 years long, but it could be to do with the dynamo effect inside the star. The Sun's convection zone contains a soup of charged particles called plasma. These particles are in constant motion, heated from below and swirled by the Sun's rotation. This creates powerful currents that set up toroidal (rings that follow the lines of latitude) and poloidal (rings that follow the poles) magnetic fields.

At different points in the solar cycle the fields change in strength, which changes the way they interact, altering the sunspots on the surface. The variations in the Sun's output across the cycle are small, but sometimes they add up to big changes on Earth. In the 16th century through to the mid-19th century, as the number of sunspots dipped, the world plunged into the Little Ice Age.

Ice ages pale into insignificance when compared to what's to come. The Sun is about halfway through its life and, as it ages, its output is set to change dramatically. When it runs out of hydrogen in its core, it will start to use the hydrogen in the shell outside. Helium will continue to accumulate beneath, and as the core gets bigger the Sun will start to swell. It will grow brighter and hotter and the fusion reactions will proceed faster and faster, until it burns more than two times as fiercely as it does today. This

will scorch the surface of the Earth, raising the temperature to more than 300 degrees Celsius.

Eventually the hydrogen will run out. Then, the Sun will ignite in a helium flash and its core will start to fuse helium nuclei, transforming them into heavier elements like carbon and oxygen. In the process, the Sun's outer layers will swell, and it will become a red giant, 34-times brighter than it is now.

The Sun will swallow Mercury and Venus, and Earth's surface will melt into pools of molten metal. By this time, the Sun will be hundreds of times brighter and hotter than it is today, and Earth's rocks will start to boil away.

When all the helium is gone, the Sun's fusion reactor will switch off. Its outer layers will cool and its atoms will blow away into space, forming a swirling planetary nebula and a white-hot core. This core, a white dwarf, will eventually cool until it is a dead, black cinder, and the light in our Solar System will go out forever.



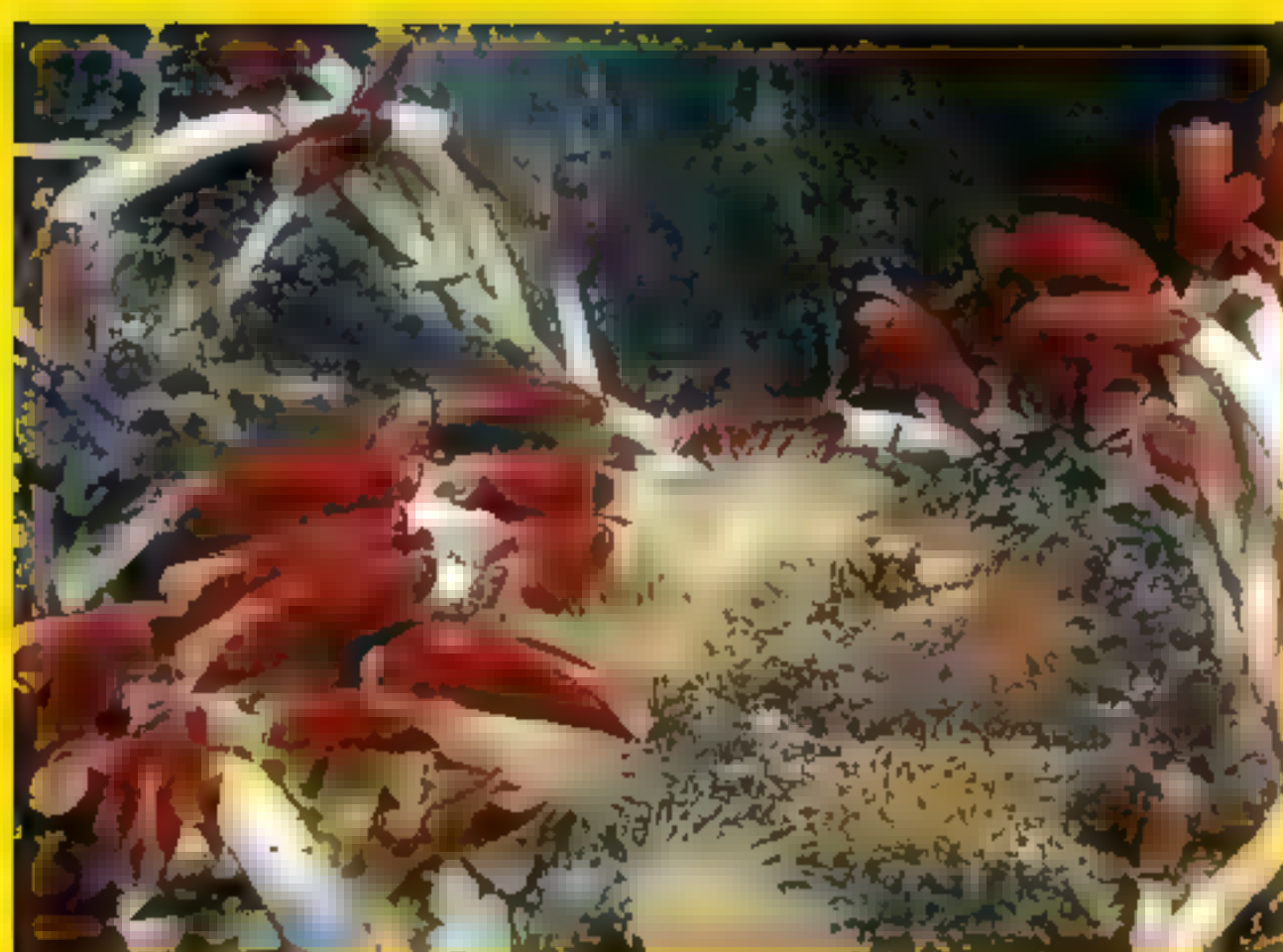
"The Sun will swallow Mercury and Venus, and Earth's surface will melt into pools of molten metal"



Lichens form when algae and bacteria capture energy from the Sun and share it with fungi

LIFE IN THE SHADOWS

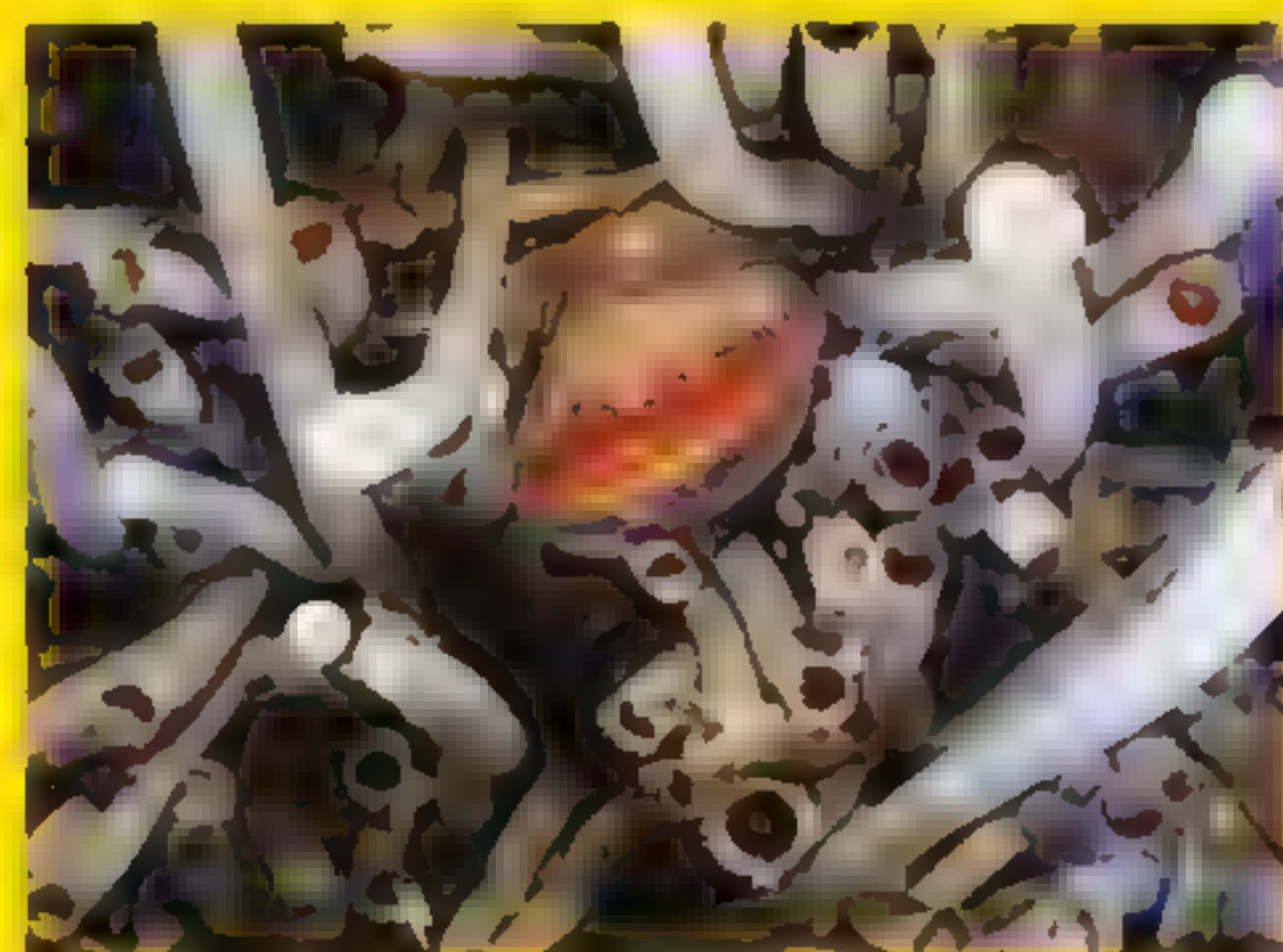
Where, in Earth's darkest places, do microbes make their energy independently of the Sun?



Hydrothermal vents

RIFTS IN THE OCEAN FLOOR

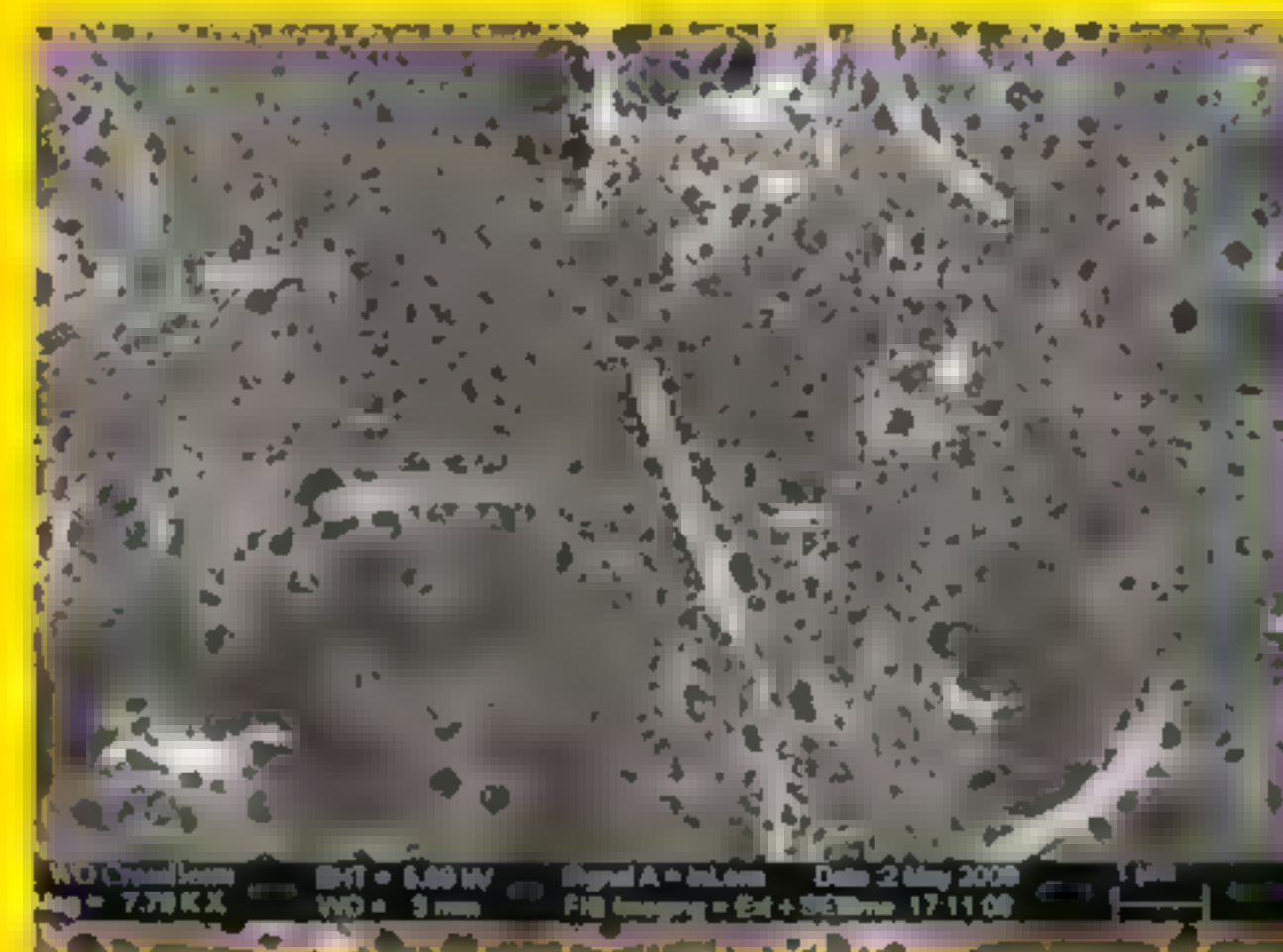
Some organisms have discovered a way to make energy from the hydrogen sulphide that leaks out from hot volcanic vents under the sea. Microbes combine hydrogen sulphide with water and carbon dioxide to make sulphur and glucose. Giant tube worms then store the microbes and use their waste to stay alive in the dark.



Methane seeps

CRACKS IN EARTH'S CRUST

Cold seeps can also sustain life without sunlight. These seafloor biomes leak bubbles of methane and hydrogen sulphide into the water, which can then feed colonies of bacteria. The bacteria form mats on the ocean floor, and they can provide enough energy to sustain beds of mussels and also groups of tube worms.



Volcanic rocks

THE CREVICES BETWEEN GOLD MINE ROCKS

The gold mine bacteria *Desulforudis audaxviator* lives in total darkness, nearly three kilometres below South Africa's surface. It survives at temperatures above 60°C with nothing but rocks to eat. It gets power from the radioactive decay of uranium and is able to extract carbon and nitrogen from the rocks.



Under Antarctic ice

BENEATH POLAR ICE SHEETS

Rock-eating microbes found 0.8 kilometres below the surface of an Antarctic ice sheet may also be able to survive without the Sun. Like their cousins in the hot hydrothermal vents, these microbes extract energy from compounds containing sulphur and also iron. But temperatures in this environment here are below freezing.

91%

Proportion of atoms that are hydrogen

¹H
1.008

70.6%

Proportion of mass that is hydrogen

5,500

degrees Celsius

Temperature at the surface

3.8×10^{26}

Watts

Power output every second



2 million
degrees Celsius

Temperature of the Sun's atmosphere

600 million tons



Hydrogen used up every second

5 billion
years

Until the helium-burning process begins

1,391,016
kilometres

Diameter at the equator

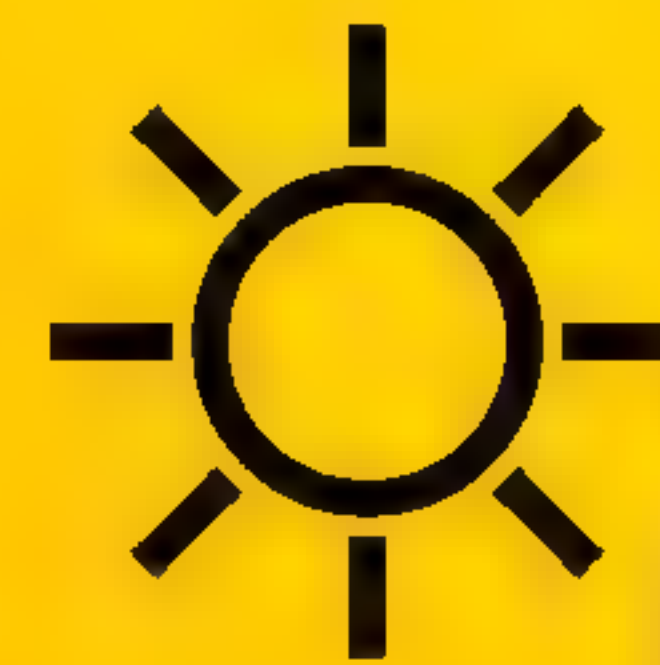
15 million
degrees Celsius

Temperature at the core



LET THERE BE LIGHT

The Sun is the powerhouse of the Solar System. So let these impressive facts enlighten you



150 million kilometres

Distance between the Sun and Earth





SCIENCE

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ROBOT SURGEON

MEET THE VR, AR AND MACHINE
INNOVATIONS THAT ARE
REVOLUTIONISING OUR HOSPITALS

Written by James Horton



The field of surgery perhaps relies more on technological innovation than any other medical practice. Yet during the Neolithic period, the final era of the Stone Age, surgery was already taking place. Trephining – where a hole would be made into the skull – was used as a proposed treatment for an ailment that still remains a mystery to us today – although the ancient Egyptians would later use the same procedure to treat migraines. Remarkably, some individuals survived this treatment long enough to undergo it a second time!

As with many things in the Western world, our understanding of surgery was bolstered by the ancient Greeks, who performed autopsies to learn about anatomy and helped the living by setting broken bones, ‘bleeding’ their patients, performing amputations and even draining fluid from lungs. The advanced Islamic world of circa 900 CE would go on to produce books on ear, nose and throat surgery and several other subjects. But without anaesthetic, antiseptics and advanced equipment, these practices remained extremely dangerous and an understandably terrifying prospect for a patient.

By the Middle Ages Europeans had at least made tentative advances in anaesthetics. Unfortunately, the concentrations of herbs and alcohol used for this purpose were about as dangerous as the surgery. They were so powerful that many patients died on the operating table before the surgeon had even started the procedure. Surgeons of this time were an interesting group, as they were mostly barbers by trade; these barber-surgeons would pull a tooth, set a bone or even perform an amputation if the need arose.

It would take until the 1800s, once the Age of Enlightenment had driven new innovations in science and technology, for an anaesthetic gas to

find widespread use. Later that same century we also came to understand germ theory and how to prevent infection following surgery – the basis of modern infection control.

This exponential progress would continue into the 20th century as antibiotics, blood transfusions and X-rays would all increase the safety and effectiveness of surgery. By the turn of the millennium, with our then-comprehensive knowledge of surgery, it would have been easy to believe that little potential remained for future progress. By then people were not only undergoing routine surgery for life-saving operations but also to improve their quality of life, or even just for cosmetic purposes. But it seems we were still just getting started.

Advances in software development and robotics hold immense promise for revolutionising surgery, and many are already making their way into the clinic. These technologies will be found in nearly every corner of the surgical practice, from training future surgeons to conducting a complex procedure.

Let’s start at the beginning. Imagine you’re a budding surgeon who’s itching to get some insight into your chosen profession. The standard process for this would have you peering over an experienced surgeon’s shoulder, sometimes travelling far afield to visit an expert based at a distant hospital. But in 2016 VR

“Advances in software development and robotics hold immense promise for surgery”



Robot surgical procedures are ideal for minimally invasive operations, which yield faster recovery times

(virtual reality) was first revealed to be an amazing technology for sharing an immersive view of a surgeon's work in real time. Surgeon Shafi Ahmed performed a live, 360-degree broadcast of a tumour-removal operation. Unlike video footage, VR enables surgical tutees to survey their surroundings, check in on other members of the surgical team and begin to imagine themselves filling the practising surgeon's shoes.

With theoretical knowledge sufficiently enhanced, the next step in your next-generation surgical training would be practice. Of course, practising surgery can be a risk-laden affair, but advanced 3D printing can provide much of the benefit with none of the risk. Physicians at the University of Rochester Medical Center, New York, successfully converted medical scans into computer-generated designs to print artificial organs that look, feel and bleed like organs and have the same mechanical properties. The aim is for these to enable aspiring surgeons to hone their skills to a high standard before beginning on actual patients. Plus, as an added benefit, 3D-printed models can be used for pre-planning and rehearsing complicated surgeries beforehand, increasing the chance of their success, even by experienced surgeons.

Imagine you're now a surgeon and we fast-forward to a day in your operating theatre: you are attempting a complicated procedure, where accurate incisions and expert guidance are paramount. Fortunately, you've graduated from virtual environments to augmented environments, and through your high-tech specs you can see the patient's internal structures mapped onto their body. An external expert from across the globe can see this too, and they are offering advice as you conduct the surgery. This augmented reality prospect, which has been championed by Microsoft's HoloLens



Virtual reality will play a role in training the surgeons of tomorrow

Seeing inside the patient

All surgeons benefit from making as accurate and small incisions as possible, but in some instances—such as spinal surgery—this accuracy becomes imperative. A pioneering new surgical technology called *Optivight* employs digital models built for patient scans with augmented reality (AR) technology to guide a patient's internal structures over their skin in real time. The digital model moves with the surgeon, providing both 2D images and 3D projections of the internal organs and tissues. This helps the surgical team to exactly the patient's pre-plan the procedure in detail and make precise incisions where the operation begins.



Optivight technology allows surgeons to see internal structures through a patient's skin in real time

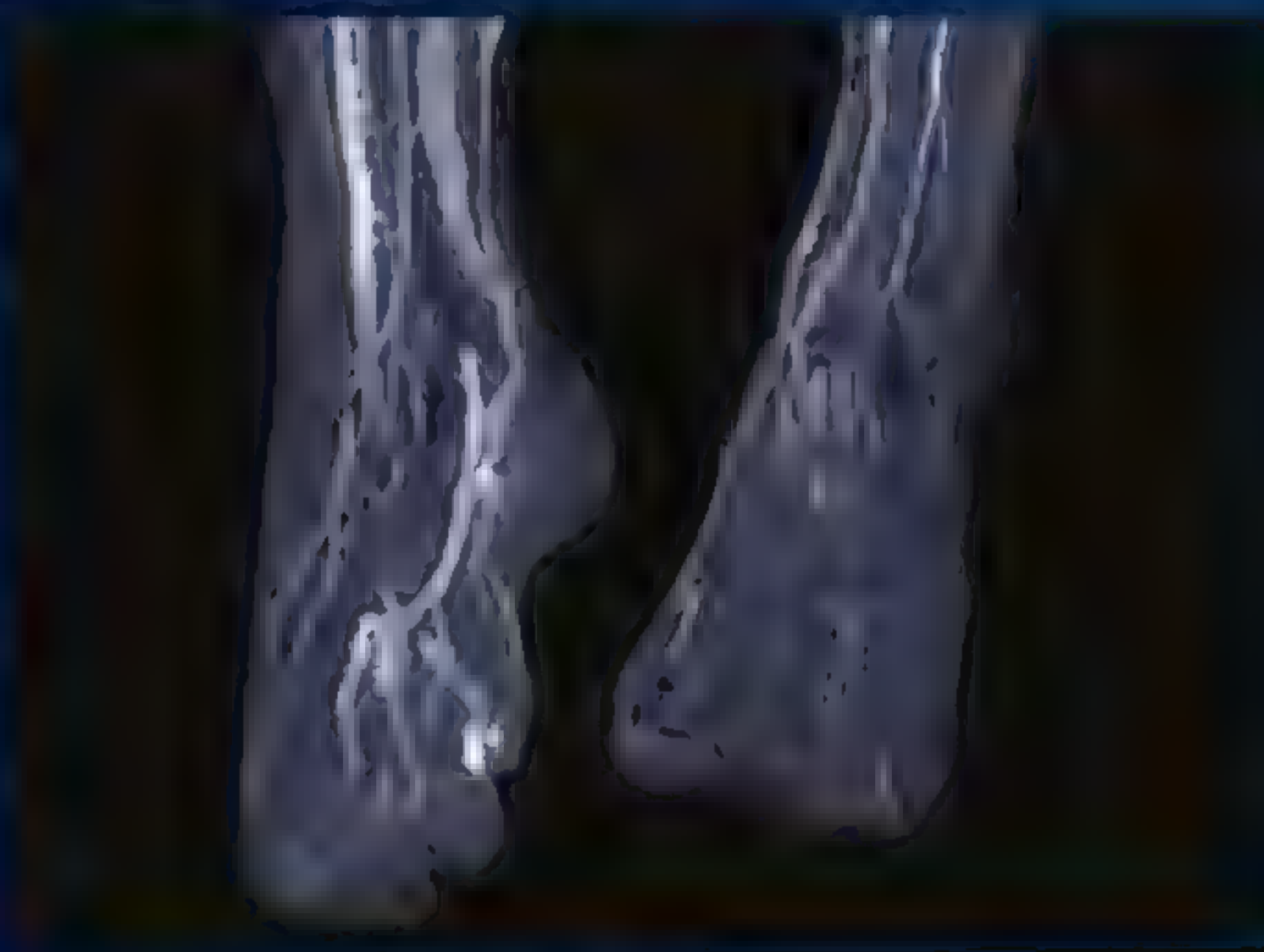
Preparing for AR surgery

Step by step, how medical practitioners are able to see through our skin during an operation



1 Scanning the body

The patient first undergoes a CT scan that captures the positions of their bones, blood vessels, connective tissues, muscles and fat.



2 Converting the scan

An algorithm pores through the scan data and creates a set of polygonal models and digital images that the surgeon's HoloLens can use.



3 Mapping the model

The generated data is mapped onto the patient, enabling the surgeon to see a digital version of the patient's interior during surgery.

Vision cart

Used by other members of the surgical team to keep up to date on progress via live-streaming video footage.

The da Vinci devices

Uncover the array of surgical systems available to today's top surgeons

The da Vinci SP

A single robotic arm hosting a 3D-HD camera and three multi-jointed instruments can be used for single-point-of-entry procedures.

Surgeon console

The main hub for controlling the da Vinci systems, the console includes hand-operated controls, foot pedal controls and a viewport.

The da Vinci X

The little brother to the Xi, this system is equipped with modular components and can be upgraded to suit the needs of the operating theatre.

The da Vinci Xi

Equipped to handle a slew of complex procedures, the Xi has advanced hardware and software and can even reposition the operating table during surgery.

technology, grants the surgeon super-human vision. Additionally, the interconnectivity between surgical teams around the world means that expertise can be shared more equally between hospitals in poorer and wealthier areas.

There are some procedures, however, where even augmented reality-equipped surgeons will be surpassed by those using robotics to enhance their precision in the operating theatre. Established robotic systems, such as the da Vinci Surgical System explored in this feature, are capable of conducting minimally invasive

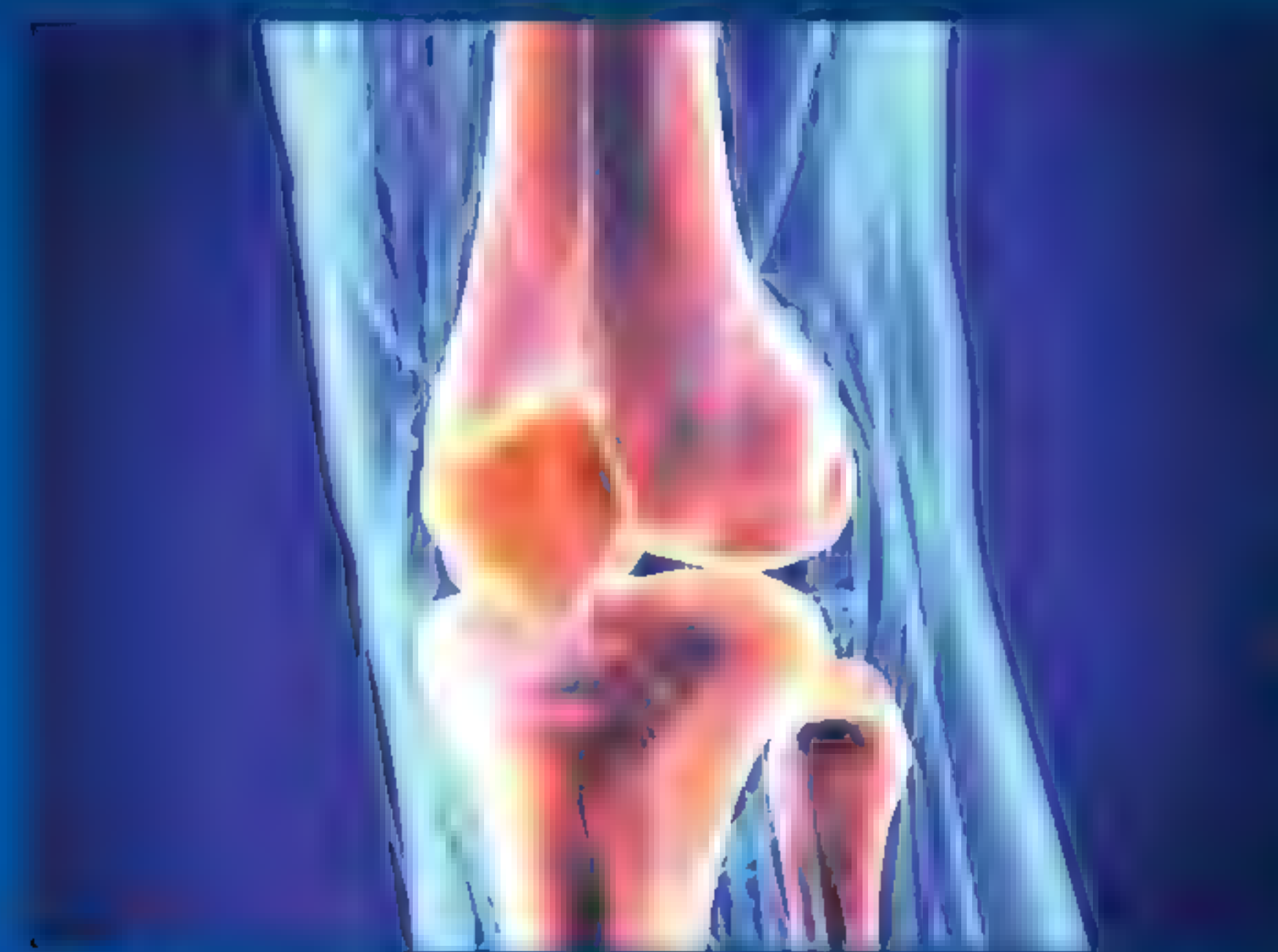
procedures that are largely unmatched by human hands. With improved dexterity, a multitude of arms and internal 3D views, robotics unlocks new possibilities in surgeries that were previously inhibited by a surgeon's limited view and restricted range of motion.

As with all technologies, surgical robotics is being increasingly miniaturised to help with implementation in an array of operating theatres and to tackle even more precise procedures. One concept that meets these aims is the Axis design, a machine that uses flexible arms with pincers on their ends to tackle eye cataract



Miniature, flexible robotic systems are being developed to treat the sensitive surface of the eye

AR technology is useful for both planning and performing surgery



4 Refining details

A mesh-processing step boosts the accuracy of the digital model, meaning the surgeon can be confident about the interior tissue's position.



5 AR surgery

The surgeon wears a HoloLens during surgery, showing them the locations of tissues and structures.



Welcome to AR theatre

How augmented reality will enhance a surgeon's ability to perform life-saving operations

A guiding hand

External surgical experts can wirelessly interact with the ongoing surgery from afar and offer advice through AR.

Sensory insight

Information is relayed from the surgical apparatus to the surgeon's head display, allowing them to make necessary adjustments immediately.

Voice control

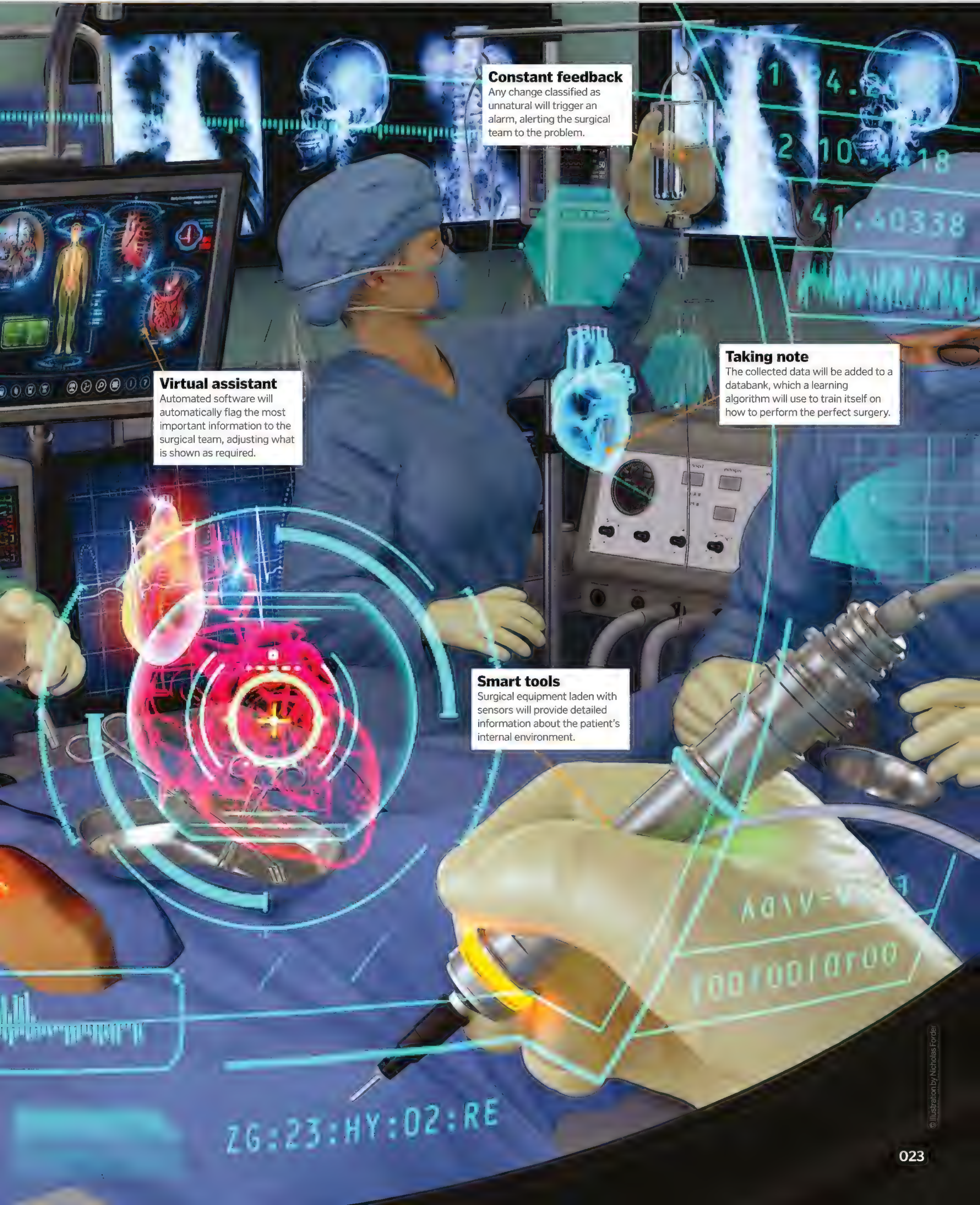
Simple voice commands can be used to clear the surgeon's augmented reality display.

Learning templates

The data collected during the surgery will also be used to create realistic training scenarios for junior surgeons.

Knowing the landscape

The patient's interior will be mapped onto the surgeon's head display, helping to guide them on the best place to make an incision.



Constant feedback

Any change classified as unnatural will trigger an alarm, alerting the surgical team to the problem.

Virtual assistant

Automated software will automatically flag the most important information to the surgical team, adjusting what is shown as required.

Taking note

The collected data will be added to a databank, which a learning algorithm will use to train itself on how to perform the perfect surgery.

Smart tools

Surgical equipment laden with sensors will provide detailed information about the patient's internal environment.

The da Vinci Surgical System

This minimally invasive equipment is just as innovative as its namesake

Minimising damage

Chest operations can be completed without the need for dividing the sternum, as the da Vinci's tools can make fine incisions between ribs.

Complete control

The robotic arms are unable to operate without direct input from the surgeon, ensuring the lead medical professional retains full control.

A better view

A 3D, high-definition vision system is enabled by tiny cameras inserted into the patient, enabling the surgeon to operate in extremely fine detail.

The operator

The surgeon guides the robotic arms by rotating, pushing and pulling a set of controls. These actions are scaled down to tiny movements.

Enhanced dexterity

Robotic arms known as EndoWrists, which possess greater rotational freedom than the human hand, conduct the surgery.

New angles, new insight

Foot pedals within the operative console are used to switch the internal viewpoint seen by the surgeon.

"Working alongside them is the AI itself, constantly learning to make predictions about points of stress in the system"

\$6.4 billion

The estimated value of the surgical robotics market by 2020

4,500+

The number of da Vinci robots worldwide of which over 70 are used in UK hospitals

750,000

The amount of remote clinical encounters facilitated by telehealth network InTouch Health

PARO, an interactive robot modelled on a seal, was designed to comfort patients in recovery

400kg

The weight of medication carried by the nursing assistant TUG robot

40

The number of times the Robear nursing robot can lift patients each day

The iKnife surgical tool heats tissue to diagnose cancer

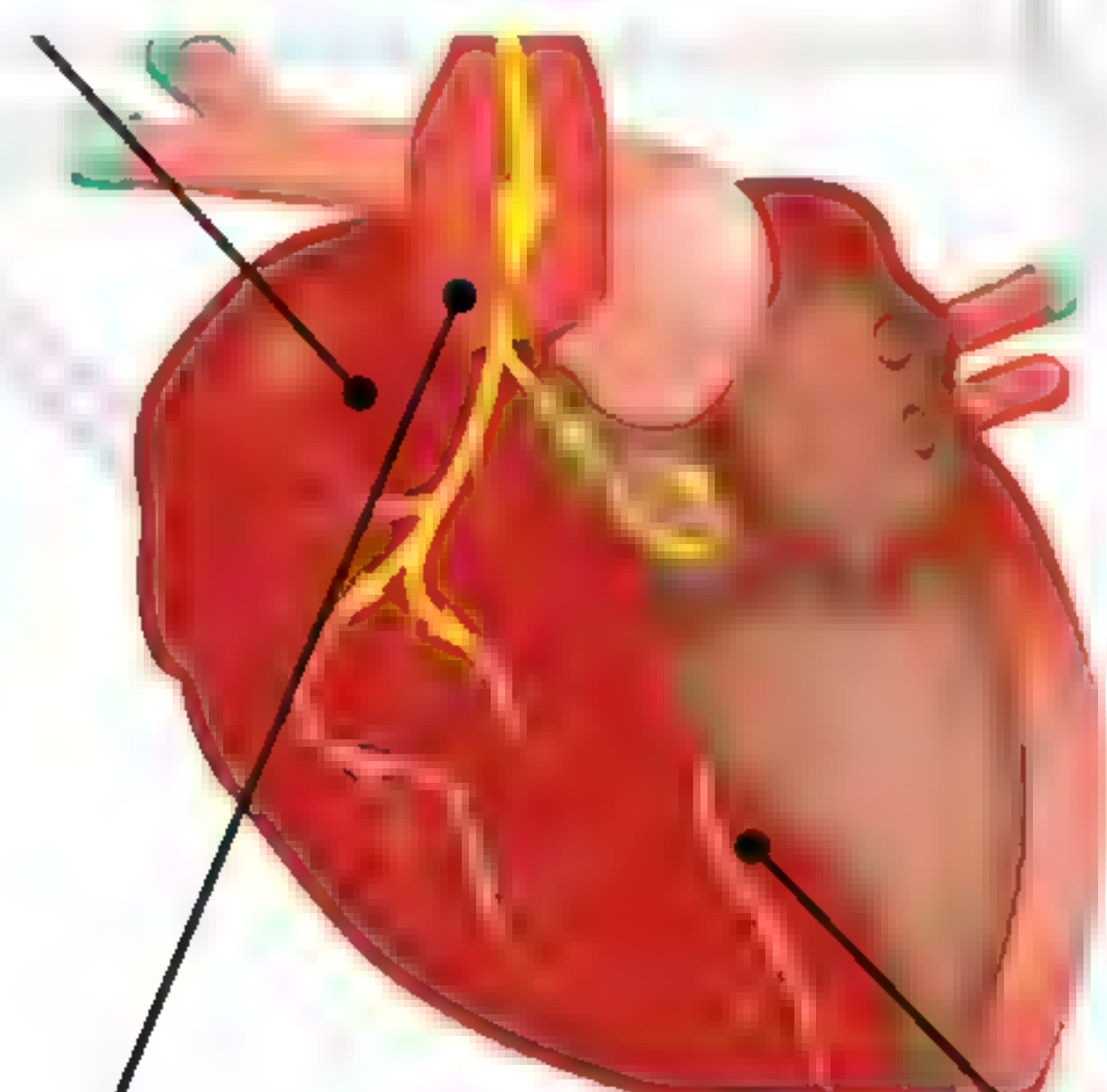
Microrobots that can migrate through blood vessels are currently being developed by the Max Planck Society

Retrofitted organs

How surgeons convert donor hearts into replacements suitable for any patient, through bioengineering

From foreign to familiar

Organ transplants can be problematic, as the recipient's immune system recognises the new organ as an intruder. By rebuilding the organ with the recipient's own cells, this can be circumvented.

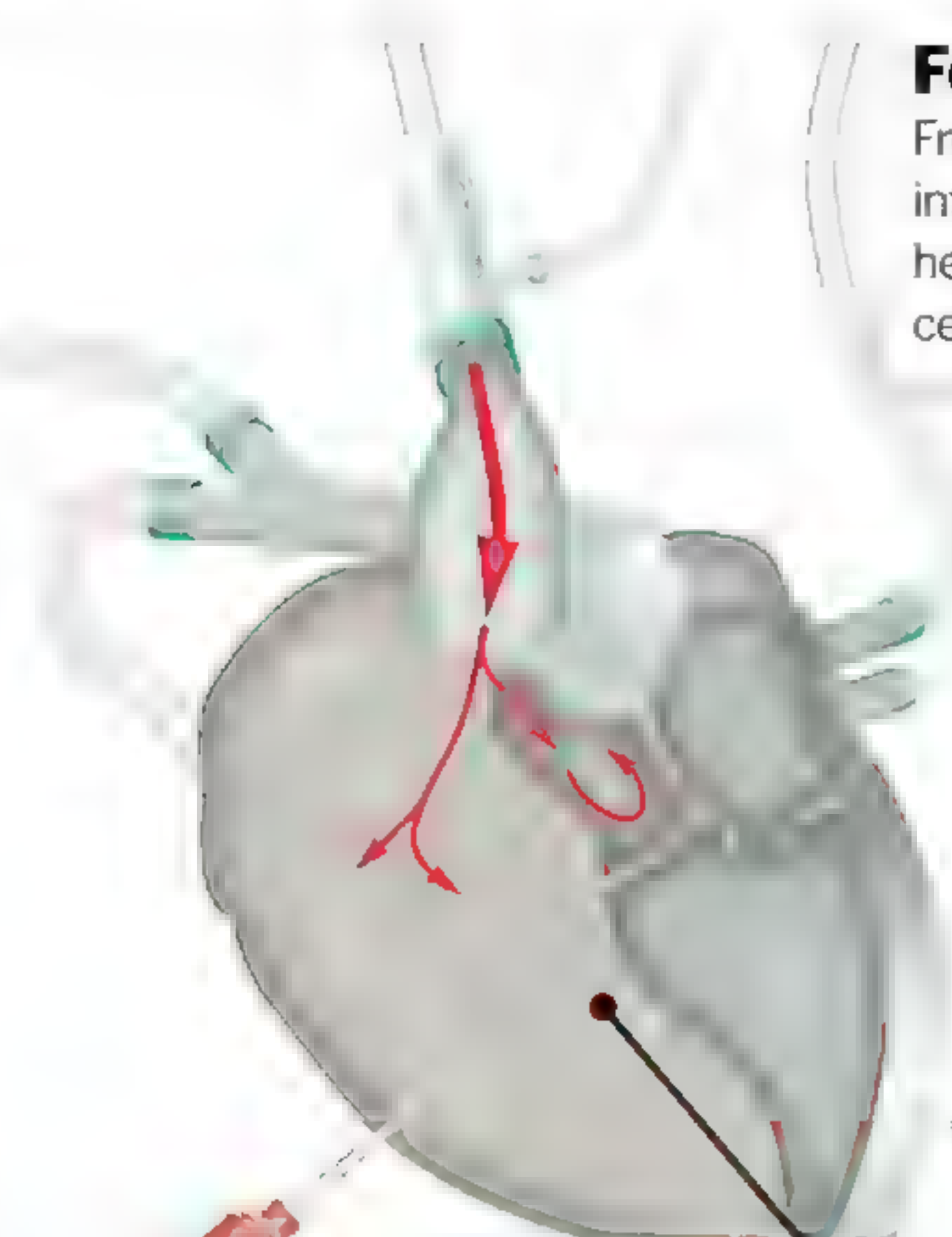


Stripping agent

Detergents are pumped into and around the heart's vessels via the aorta.

Clearing out

These detergents strip the vessels of their cells by dissolving them and carrying the debris away, leaving only the protein scaffold behind.

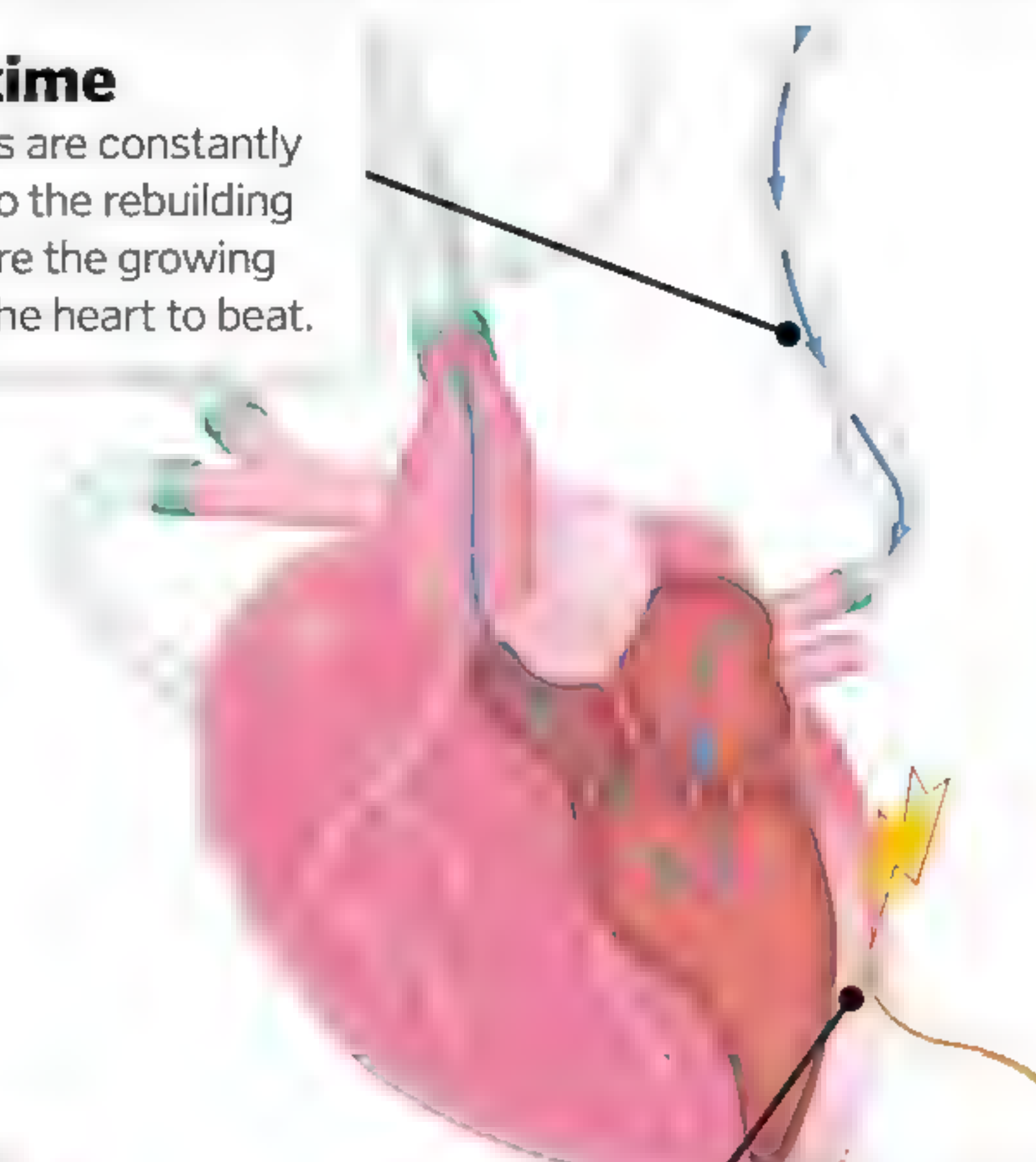


A blueprint

Stem cells are injected into the heart and attach to the protein scaffold, responding to it and becoming specialised cardiac cells.

Feeding time

Fresh nutrients are constantly introduced into the rebuilding heart to nurture the growing cells, forcing the heart to beat.



Resurrection

Electrical stimulation is used to contract and strengthen the heart muscles, helping them to beat unassisted in the future.

© Illustration by The Art Agency/Andy Gauthier

surgery. The accuracy of the 1.8mm arms are reinforced by image-guidance software and an artificial intelligence that will advise and inform the medical practitioner during surgery.

The miniature technologies may not stop there. NASA has partnered with medical company Virtual Incision to create a small robot that can be operated remotely by a surgeon for small operations in low gravity. If it's a success, we may find these robots in use on Earth too.

Tools such as Axisis, da Vinci, HoloLens and others are driving the future of surgery to a point where we have better educated, trained, connected and equipped surgeons than ever before. And like the transformations in surgery that happened throughout the previous century, we can be hopeful that progress of the same scale is on the agenda.

Learn more

Continue to engage with the future of surgery by visiting: futureofsurgery.rcseng.ac.uk. This visionary site was pioneered by the Royal College of Surgeons and is the brainchild of 14 surgical experts.

Better care

The new command centre will lead to a more efficient and effective operation at the 800-bed hospital.

Surgery command centre

As the world of surgery evolves, in all fields, especially medicine, we are collecting mountains of data almost at increasing speed. But what happens to all this data? How do we make the best use of it? To ensure they make the best use of patient data and their time, RCG, Healthcare and the Bradford Royal Infirmary have teamed up to create an AI command centre. Equipped with a wall of analytics showing the most important information,

the command centre will be a central platform for the hospital to coordinate the operation. The command centre will be a central platform for the hospital to coordinate the operation. The command centre will be a central platform for the hospital to coordinate the operation. The command centre will be a central platform for the hospital to coordinate the operation.

Advanced algorithms

Algorithms will assist staff to spot bottlenecks before they occur, helping to prevent issues from arising.

Specified teams

Up to 20 staff at a time will focus on specific areas, such as bed management, staff coordination and OR management.

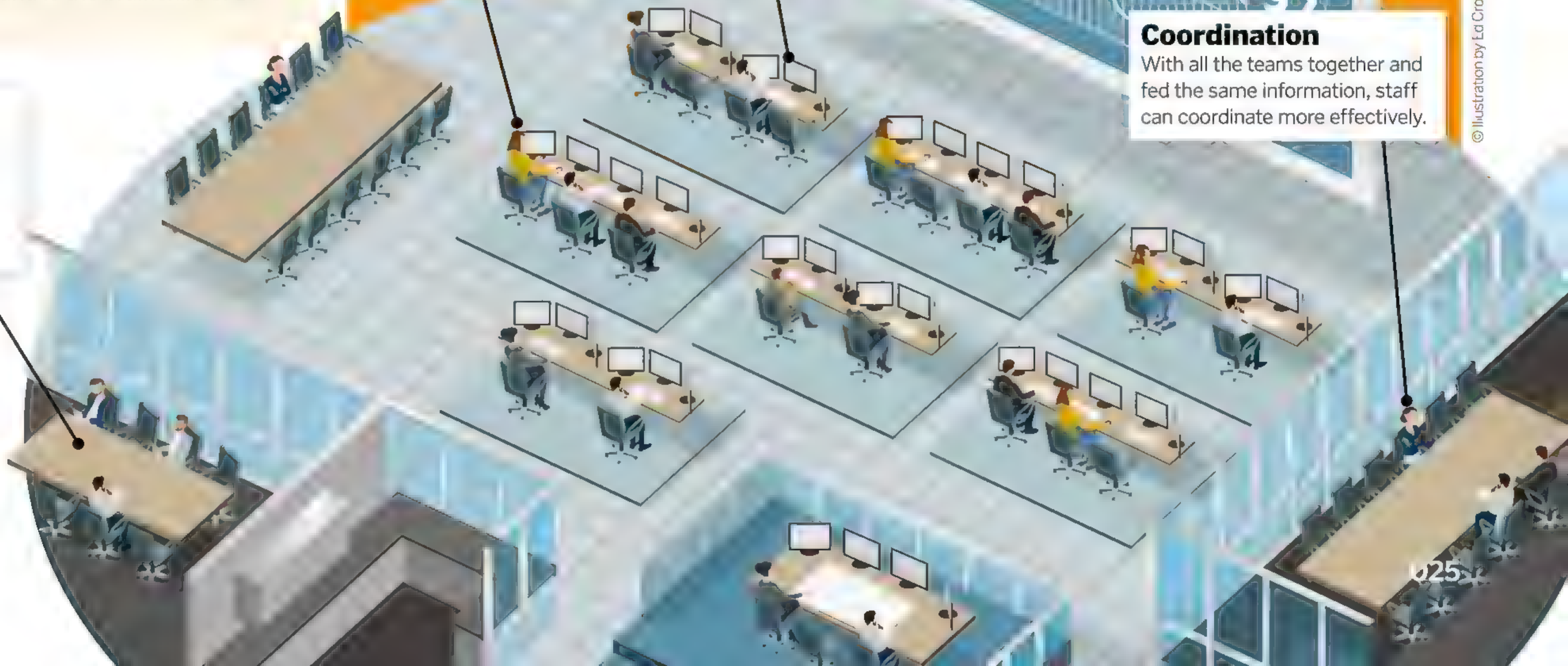
Wall of analytics

This giant display will relay crucial real-time information to the teams in the command centre.

Coordination

With all the teams together and fed the same information, staff can coordinate more effectively.

© Illustration by Ed Crooks





The World Health Organization recommends that everyone has ten routine immunisations

How vaccines save lives

These injections, drops and sprays train your immune system to fight deadly diseases

Made up of millions of individual white blood cells, the immune system patrols the body in search of germs. When tissues are under threat, it mounts a two-pronged attack. First, the innate immune system gets to work to slow germ growth and prevent spread. Then the adaptive immune system comes in to eliminate the threat.

The adaptive immune system has powerful weaponry, but it takes a while to deploy. This is because the cells of the adaptive immune system can each only attack one type of infection. When the body encounters a new germ, it needs to find the right cells and prepare them for battle. This process can take up to one week, and in that time people can sometimes become very unwell.

This is where vaccines come in. Rather

than wait to encounter a dangerous disease like measles in the world, a vaccine gives the immune system a chance to prepare in advance. Vaccines contain weakened or dead germs, or parts of germs, along with something called an adjuvant. This helps to alert the immune system to danger, encouraging it to start mounting an attack. With access to parts of the germ, the immune system can find the right cells and get them ready.

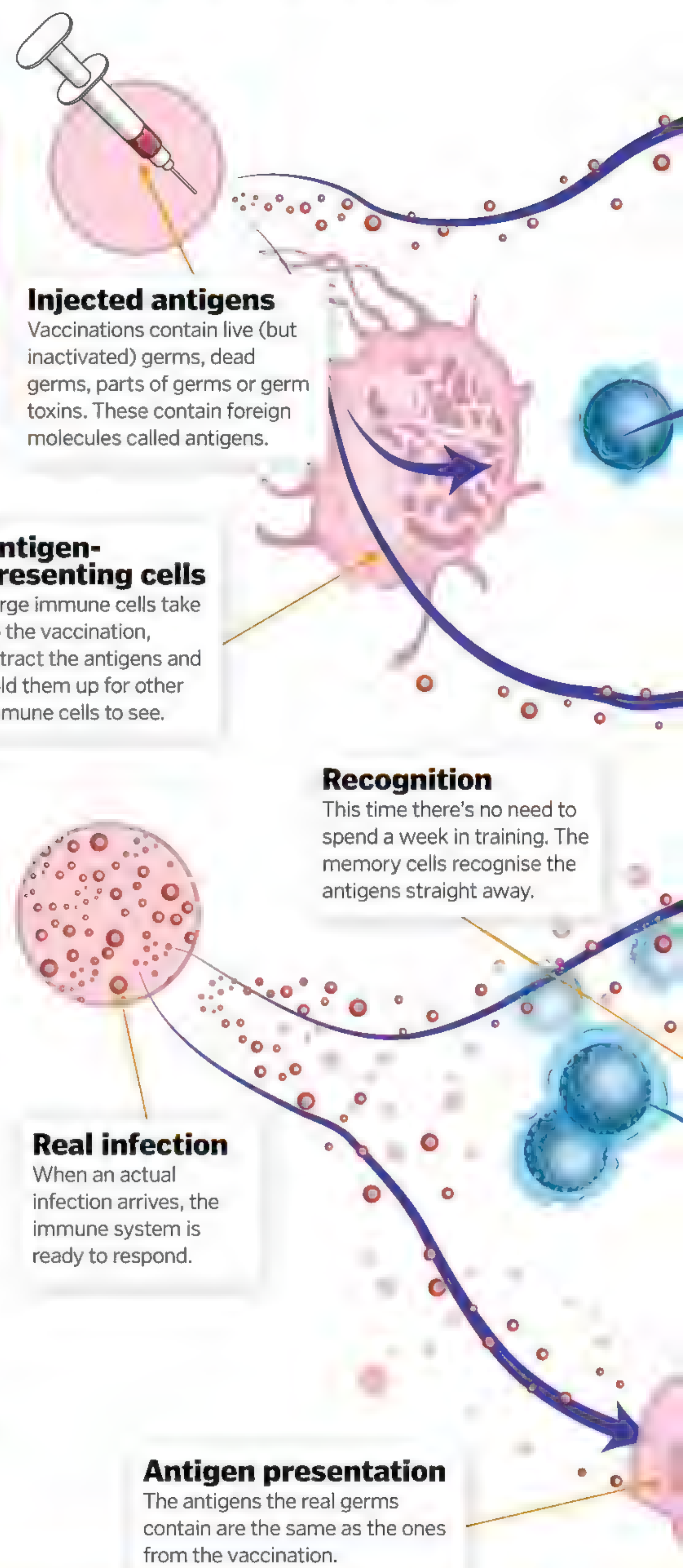
Many of the cells made during a vaccination disappear afterwards, but some stick around as 'memory cells'. They stay in the bloodstream for decades, constantly on the lookout for their matching germ. If the infection then happens for real, these memory cells spring into action straight away. They divide to produce an army of clones that appears in a matter of hours instead of days. This can clear the infection before it takes hold, preventing us from getting sick at all.

Falling vaccination rates are causing measles outbreaks in the US and Europe



What happens when you're vaccinated?

Vaccinations prepare the immune system to fight infections with speed and precision



Are vaccines dangerous?

Without our current vaccinations, 2.3 million children would die every year. If we used the same vaccination to immunise more children, we could save 1.5 million more lives. But in some countries vaccination rates are dropping. To stop the spread of measles, 95 per cent of children need to have had their MMR vaccine, but in England in 2017-18 uptake was only 94.2 per cent. At this level herd immunity stops working and the virus can start to spread.

There are some concerning vaccine myths, but the truth is that vaccinations save lives. Babies are able to cope with millions of germ cells every day. Vaccinations don't overload or weaken their immune systems, even if they were more potent. It's safe to vaccinate, even if they have a cold, flu or allergies. There is absolutely no link to autism. And if you or your children haven't had vaccinations, it's never too late to go and get them.

First encounter

Cells called lymphocytes come to inspect the antigens from the vaccine. Only some will be able to fight the infection.

Training the army

It takes about one week to find the right lymphocytes and get them ready for battle.

Memory cells

Some lymphocytes turn into memory cells, which stay in the blood in case the infection returns.

Destruction

The immune system responds rapidly, destroying the germs before you even know you're infected.



Before vaccinations, iron lungs helped children to breathe when polio paralysed their muscles

5 FACTS ABOUT HOW VACCINES SAVE LIVES

1 Smallpox

Smallpox used to kill 5 million people every year. Now it kills none. Thanks to a worldwide vaccination campaign the disease disappeared in 1980 – the only infectious disease to have been eradicated.

2 Diphtheria

The skin and respiratory infection diphtheria would kill 260,000 people every year if it weren't for vaccination. Immunisation prevents at least 86 per cent of infections worldwide.

3 Whooping cough

Without vaccination, there would be nearly 1 million deaths from whooping cough every year. Immunising young babies has reduced that number by two-thirds.

4 Measles

Measles can cause blindness, brain swelling and severe lung problems. It takes just two doses of the vaccine to protect children from infection, preventing 2.6 million deaths every year.

5 Neonatal tetanus

Newborn babies are especially vulnerable to tetanus infection. Thanks to vaccination, 700,000 more babies are now surviving every single year.

Next-gen vaccines

The science of immunisation is only just beginning. The Human Vaccines Project is bringing the world's top scientists together to unlock the secrets of immune response. To design the vaccines of the future we need to understand our own immune defences. The Human Immunome Program is mapping the genes that allow the immune system to make custom antibodies for different germs. The Rules of Immunity Program is discovering what rules the immune system. The more we know about how our immune system army works, the better we'll get at training it to fight disease.

Flu viruses change every year, so we have to change our vaccines to keep up



How we taste

Explore the body's fifth sense and how our tongues translate chemical information to our brains

Taste is produced by the body's biological translation of flavour. The responsibility of detecting taste, however, doesn't fall solely on the tongue, as it works in tandem with the nose.

Before any food has reached the mouth, olfactory (smell) receptors are triggered by volatile odorants (smell compounds) entering the nasal canal. A series of electrical impulses, called action potentials, are created along the adjoining nerve cells, which inform the olfactory cortex of the brain about the scent's identity.

This is when the tongue's role completes the decryption of a food item's taste. Spread across the length and breadth of the tongue are small bumps called papillae. Often mistaken as taste buds, these protrusions are the gateways to taste perception. Around 50-100 taste pores/buds are held in the cellular walls of a papilla and detect the chemical composition of food, dividing it into five categories: sweet, bitter, salty, sour and umami (savoury). Foods high in sodium chloride trigger a salty taste, hydrogen triggers sour, sucrose leads to sweet, quinine brings bitter and glutamate (a savoury food compound) results in umami.

However, it is a common misconception that these five tastes are only detected in certain regions of the tongue. In fact, each one can be detected all over. Once a chemical is detected, neurons carry electrical impulses to the brain, informing it of which flavour has been activated.

Together with the information obtained by smell, a conclusion can be drawn about what you're eating and how it tastes. This is why, by pinching your nose while you eat, the brain can detect if the food is sweet or sour but not its distinct flavour.

The science of spice

Feeling the initial burn of a jalapeño pepper, you might expect spice to be classed as one of the core categories of flavour, alongside sweet and sour. However, the tongue's perception and the body's reaction to spicy food is a result of a chemical crossover. For the purpose of preventing the body ingesting hot (temperature) food, vanilloid/capsaicin receptors on the tongue alert the brain when extreme heat is present in the mouth. Eating chilli peppers has the same effect on the body thanks to their chemical composition.

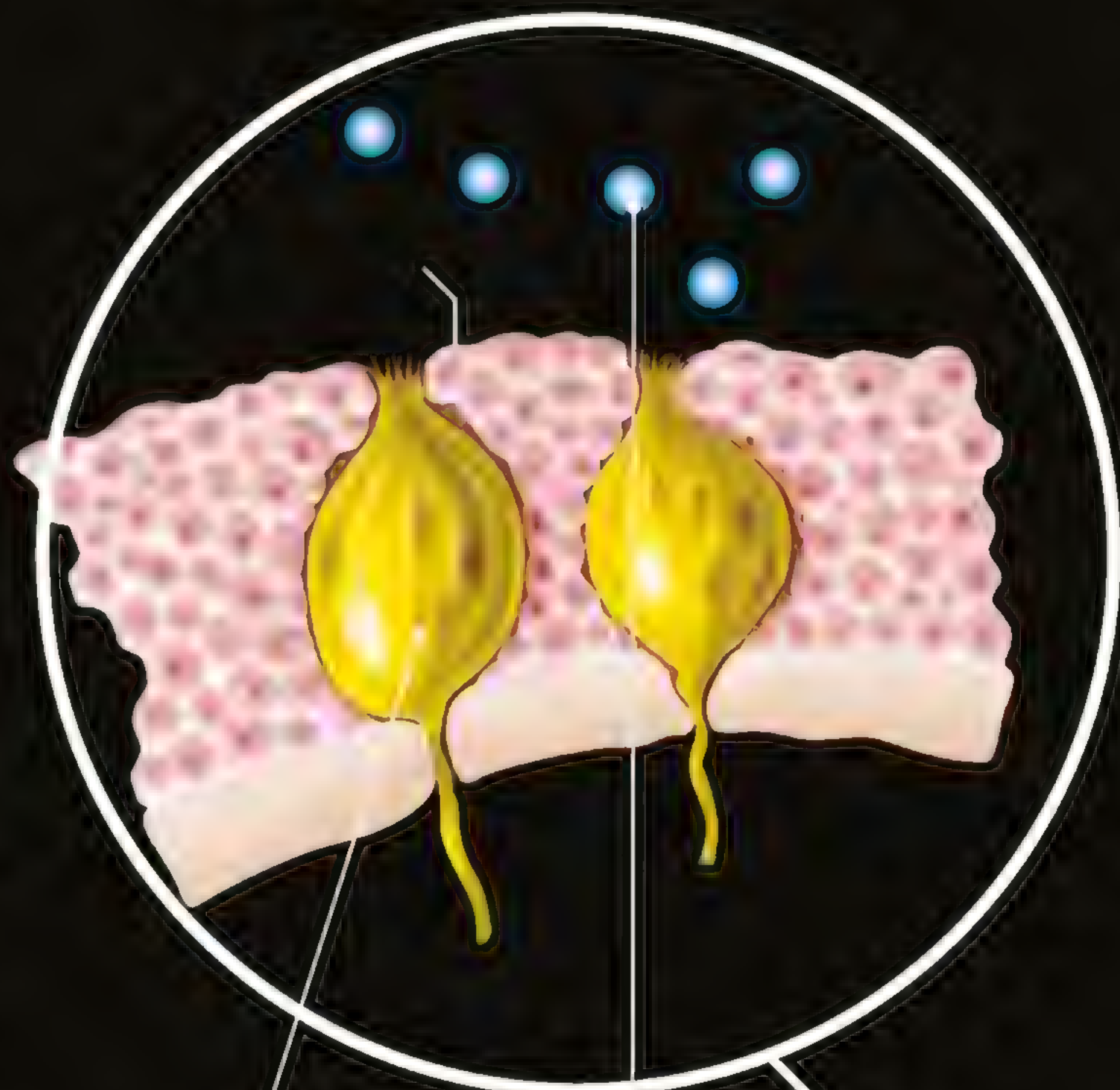
Varying in degrees of concentration along the Scoville scale, capsaicinoids are a chemical compound found in spicy food and activate the capsaicin receptors. Just like when you eat hot food, the body's response to spice is to perspire to cool down, release endorphins and increase blood circulation. So rather than being classed as a flavour, spice is merely a chilli's ability to masquerade as heat.



The world's hottest chilli is the Carolina Reaper - it's 200-times hotter than a jalapeño pepper.

From fork to frontal lobe

Discover the chemical journey that triggers our ability to enjoy food

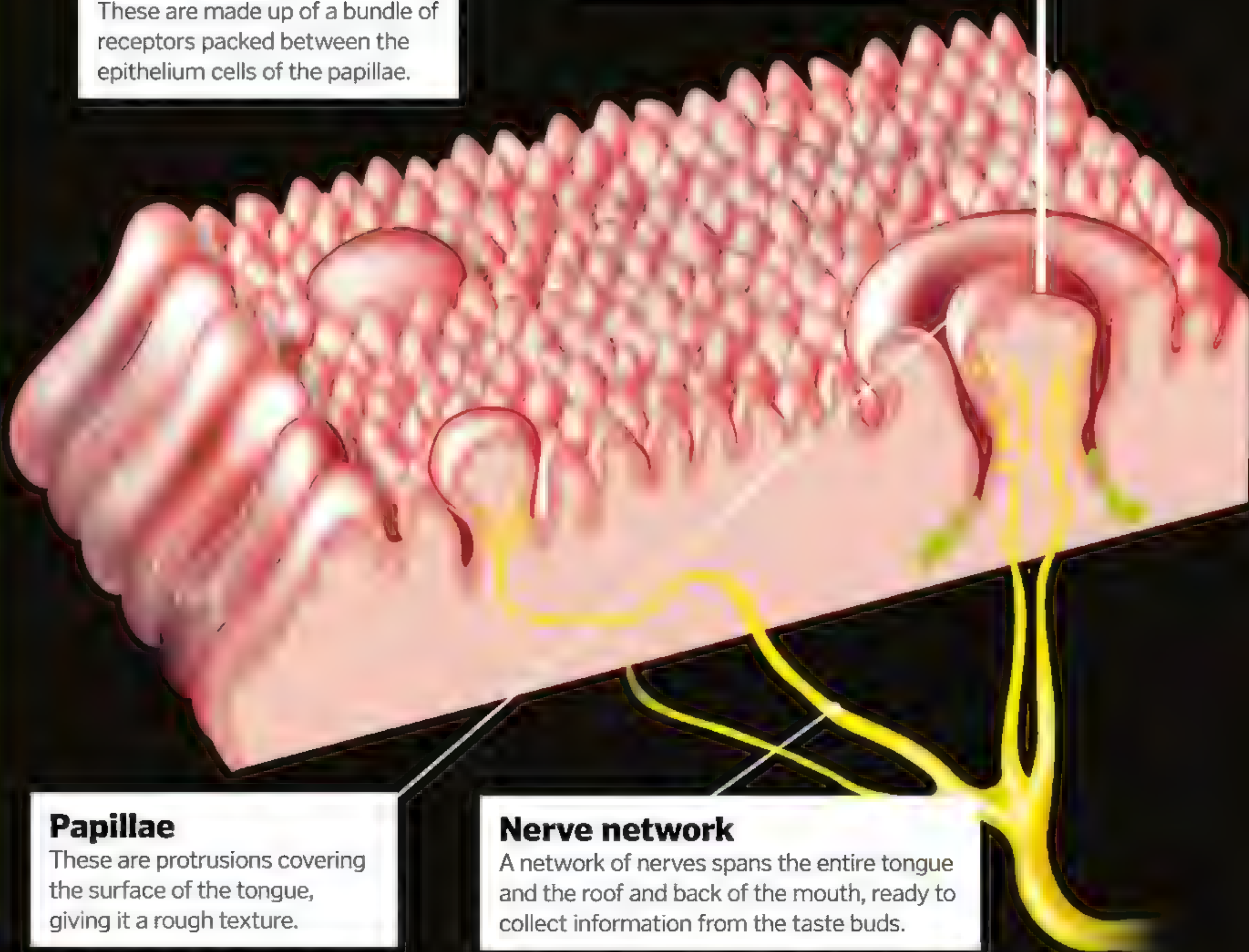


Receiving food

Gustatory hairs, extending from the taste buds, receive food chemicals that have been dissolved in saliva.

Taste buds

These are made up of a bundle of receptors packed between the epithelium cells of the papillae.



Papillae

These are protrusions covering the surface of the tongue, giving it a rough texture.

Nerve network

A network of nerves spans the entire tongue and the roof and back of the mouth, ready to collect information from the taste buds.

Olfactory bulb

Chemical information, relayed via the olfactory bulb and neurons, delivers the information to the brain's olfactory cortex.

Gustatory cortex

Impulses arrive from the tongue at the gustatory cortex, where they are translated, resulting in the brain's response of secreting saliva in the mouth.

Smell

Odorants enter the nose and are detected by olfactory receptors in the nasal cavity.

Cranial nerves

Three of the 12 cranial nerves are used in the perception of taste; the glossopharyngeal, facial and vagus nerves.

Healing a burned tongue

Taking a bite of piping-hot pizza or sipping a mouthful of scalding coffee too soon can lead to your scorching tongue. It's not all unpleasant at one time or another. Actually, almost all of us have a burnt tongue. It's caused by a first-degree burn but quickly heals in a day or two.

But why don't burnt taste completely the whole mouth by accident? When we scald the surface of our tongue, we remove the top layer of cells, including the upper part of our taste buds. However, within the bundle of these cells are stem cells known as basal cells.

Typically, containing the auxiliary material with every two days or so, these multipotent cells migrate into replacement receptors rapidly, restoring your taste. That's why you take another bite of pizza.

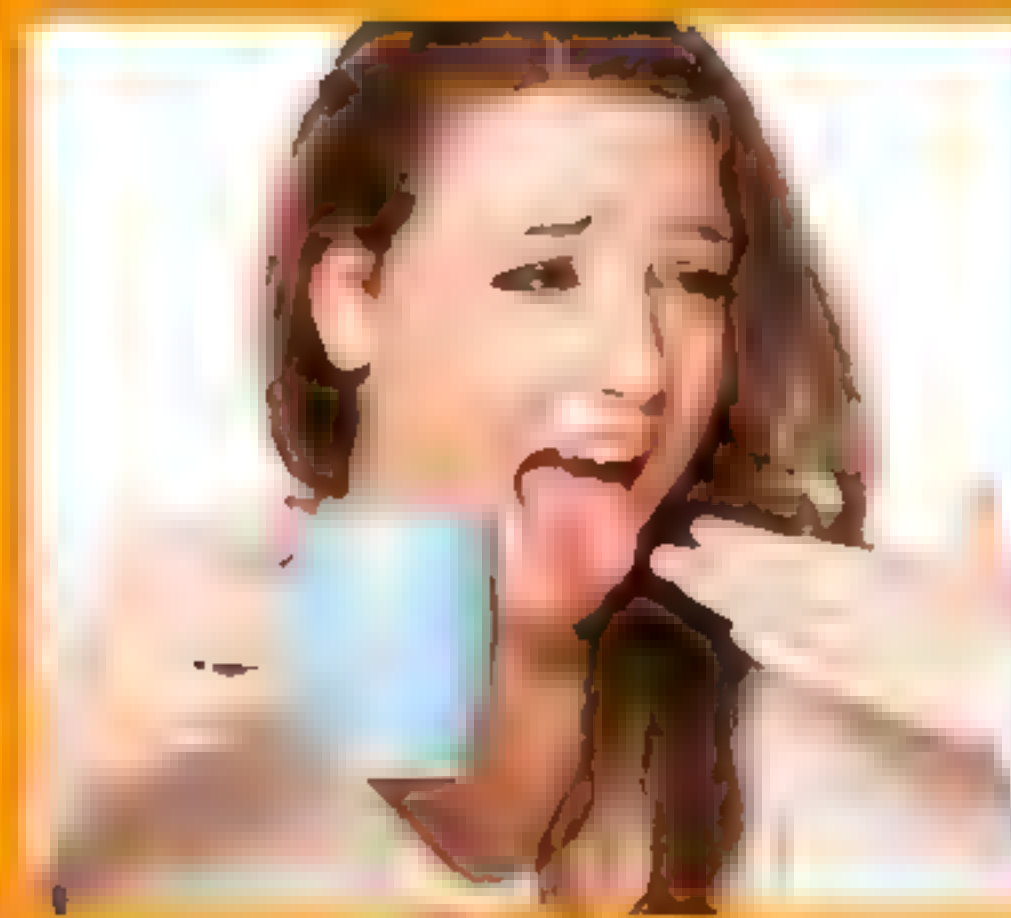


Illustration: Shutterstock.com
Photograph: iStockphoto.com

Flavour transmission

Having received the dissolved chemicals, an action potential is generated by the taste buds, sending electrical information through the adjacent nerve cells to the brain.



What was the CHERN



CHERNOBYL disaster?

Explore the site of the world's worst nuclear accident and discover how it has made an incredible recovery

Words by **Laura Mears**

When the Chernobyl nuclear reactor exploded in 1986, it released five per cent of its 200-ton radioactive core into the atmosphere. Radiation doses around the reactor rose from a safe average background level of two millisieverts (mSv) to over 20,000 mSv. It was the worst nuclear accident in history, but, 33 years later, the environment has made a recovery that has astonished experts.

Immediately after the explosion, hundreds of plant staff and firefighters began the battle to contain the fallout. They flooded the reactor with up to 300 tons of water an hour and even tried sending robots in to collect the flaming debris. To stem the blaze and block the radiation, pilots began to fly back and forth over the hole left by the explosion, dropping radiation-absorbing materials onto the exposed radioactive core: boron to absorb neutrons, dolomite to absorb heat, lead to block radiation and sand to weigh everything down. In total, they made roughly 1,800 flights, depositing 5,000 tons of materials.

As they worked, dust and debris from the explosion climbed a kilometre into the air, and wind blew the fallout – radioactive dust and particles from the reactor that literally fell out of the sky – to the northwest. The most dangerous particles were caesium and iodine, both of which get into the food chain and can cause damage to DNA. The caesium-137 particles were large, so they didn't travel far. They collided with trees and buildings close to the power plant and coated the ground when it rained. They settled on skin and clothes, entered rivers and streams and seeped through the soil into the groundwater. This contamination covered an area spanning 200,000 square kilometres around the site.

The iodine-131 particles were smaller, allowing them to travel further. They rose high into the sky, scattering across Europe, with some traces reaching as far as the US and Japan.

The most immediate danger was to the people in the surrounding area. Those within 4,300 square kilometres were at risk of a potentially deadly lifetime radiation exposure of more than 350 mSv. Some of the 45,000 residents of the nearest town, Pripyat, had already received 50 mSv of radiation. So they, and more than 150,000 others in the surrounding area, had to evacuate. To this day, a 30-kilometre exclusion zone remains in force around the reactor, and it has been deemed too dangerous for humans to return to for at least 20,000 years.

As residents moved out, hundreds of thousands of workers moved in. These 'liquidators' washed radioactive dust from the streets with a thick liquid they called molasses. They bulldozed dead trees, buried broken equipment and knocked down contaminated buildings. They received radiation doses of between 100 and 500 mSv, putting their own health at risk. Of those that responded first, 237 became ill with acute radiation sickness. But, thanks to their work, radiation levels in the exclusion zone started to drop.

As time has passed, radioactive decay has made the exclusion zone even safer. Iodine-131 has a half-life of just eight days, and caesium-137 a half-life of 30 years. As the years go by, the danger from radiation is steadily falling.



Trees have flourished in the town of Pripjat in the years since the disaster



The exclusion zone is home to hundreds of stray dogs, descended from abandoned pets

When the accident happened, the worst of the fallout hit the trees. They absorbed between 60 and 90 per cent of the radioactive cloud, experiencing radiation levels of 5 mSv an hour. As a result, 400 hectares of pine forest turned red and died, taking bees, butterflies and spiders with it. As rain washed the particles into the clay soil and new trees started to grow, the radioactive particles began to cycle through the ecosystem. They got into mushrooms on the forest floor, lichens on branches and from there into grazing animals like elk and deer. But, as the years since the disaster have passed, the forest has started to recover.

Birch and aspen trees have grown up in place of the damaged pines. They still take in radiation from the soil, but animals have started to return. Mouse and vole numbers have returned to normal, and larger animals are taking advantage of the empty spaces left by humans.

What caused the meltdown?

The night of the disaster, shift supervisor Aleksandr Akimov received orders to test reactor 4 at the Chernobyl Nuclear Power Plant. The plant worked by pumping water past hot nuclear fuel, creating steam, which drove two turbines. His superiors wanted to know what would happen if the main electricity cut out, so they disabled some of the automatic safety features to conduct a test. Worried that it was a bad idea, Akimov resisted, but eventually he agreed to shut the system down for 20 seconds. However, the control rods that should have slowed the nuclear reactions actually caused the power to surge. The water in the reactor boiled, the pressure rose and the 1,000-ton reactor top broke free. This jammed the control rods, and the tubes containing the nuclear fuel started to crack. Then the reactor exploded.



Helicopters dropped sand on the reactor in an attempt to contain the radiation

Timeline of Chernobyl

27 APRIL 1986

Helicopters make hundreds of trips over the reactor, dropping sand, lead and boron to absorb the radiation.

NOVEMBER 1986

Liquidators complete construction of a concrete sarcophagus, covering the remains of the reactor.

26 APRIL 1986

Reactor 4 at the Chernobyl Nuclear Power Plant explodes, and firefighters battle to put out the blaze.

10 MAY 1986

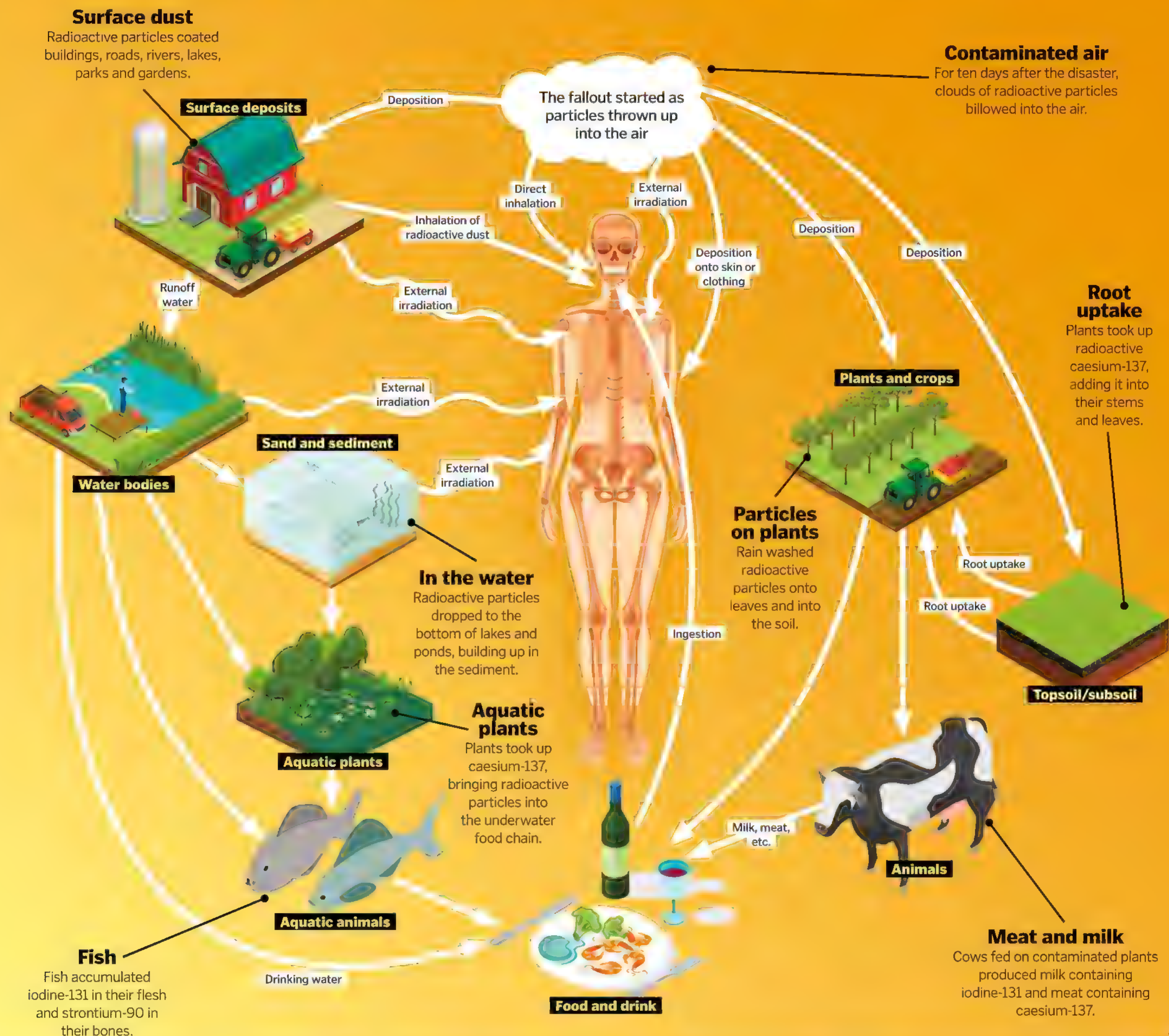
Roughly two weeks later, the fire inside reactor 4 is finally extinguished.

1987-1991

Hundreds of thousands of liquidators work inside the exclusion zone to wash, bulldoze and bury contaminated buildings and trees.

HOW THE RADIATION SPREAD

Nuclear fallout moved through the environment in the days, weeks and months after the disaster



④

1991

Chernobyl's three other nuclear reactors are still running. A fire in reactor 2 convinces authorities to shut it down.

2015

Census data reveals that elk, roe deer, red deer and wild boar are thriving inside the zone.

2018

The Chernobyl Power Plant gets a new lease of life with 4,000 new solar modules.

2011

Radiation levels have dropped. Ukraine's Emergencies Ministry starts allowing tourists to visit.

2016

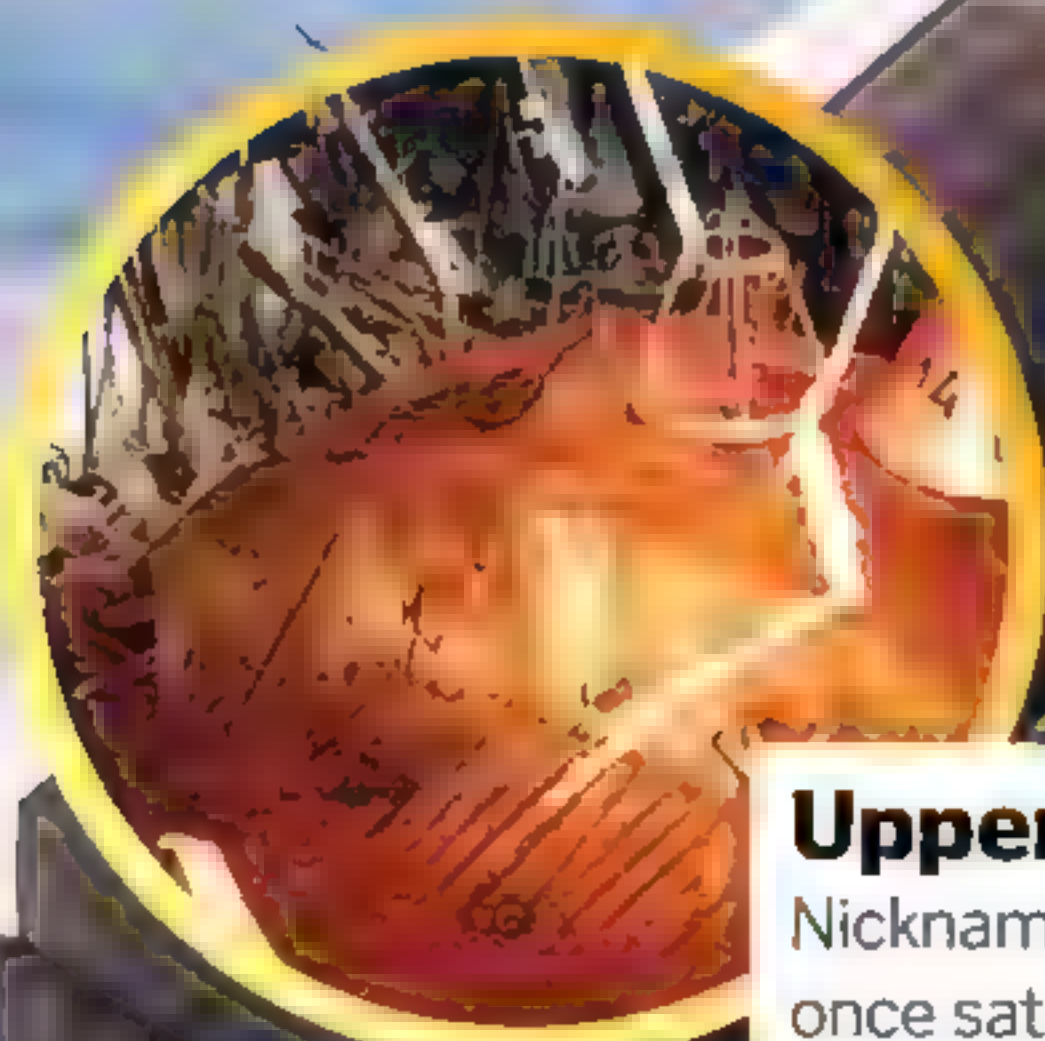
The New Safe Confinement shelter slides into place over the old sarcophagus.

- 2019

Radiation levels just outside the New Safe Confinement now barely rival a dental X-ray.

INSIDE REACTOR 4

Before and after the nuclear reactor exploded on 26 April 1986



Upper biological shield

Nicknamed 'Elena', this concrete slab once sat above the reactor. Now it lies at an angle, fuel cells still attached like hair.



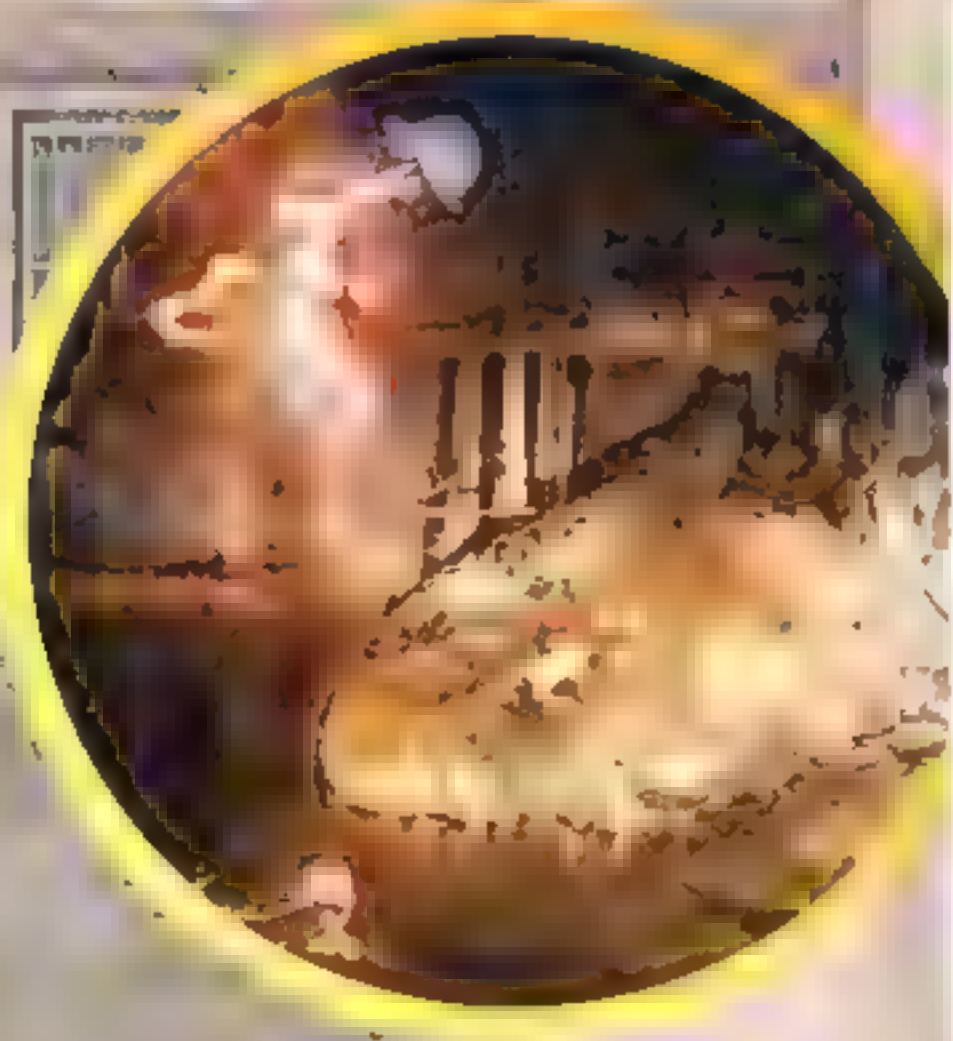
Water pump

Before the disaster, energy from the turbines fed back to water pumps, which sent cooling water to the reactor.



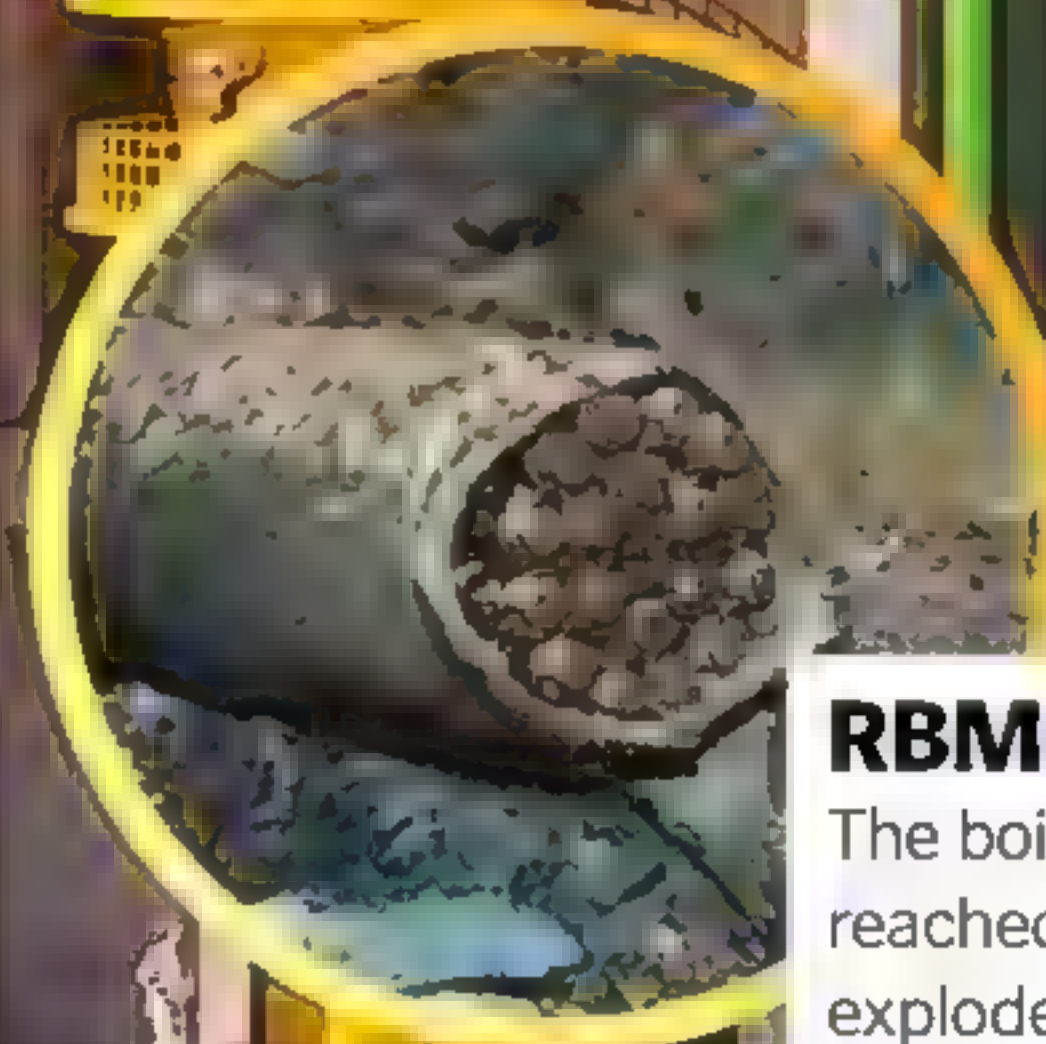
Control rods

These rods were supposed to absorb neutrons and slow the reactor. They became stuck when the reactor exploded.



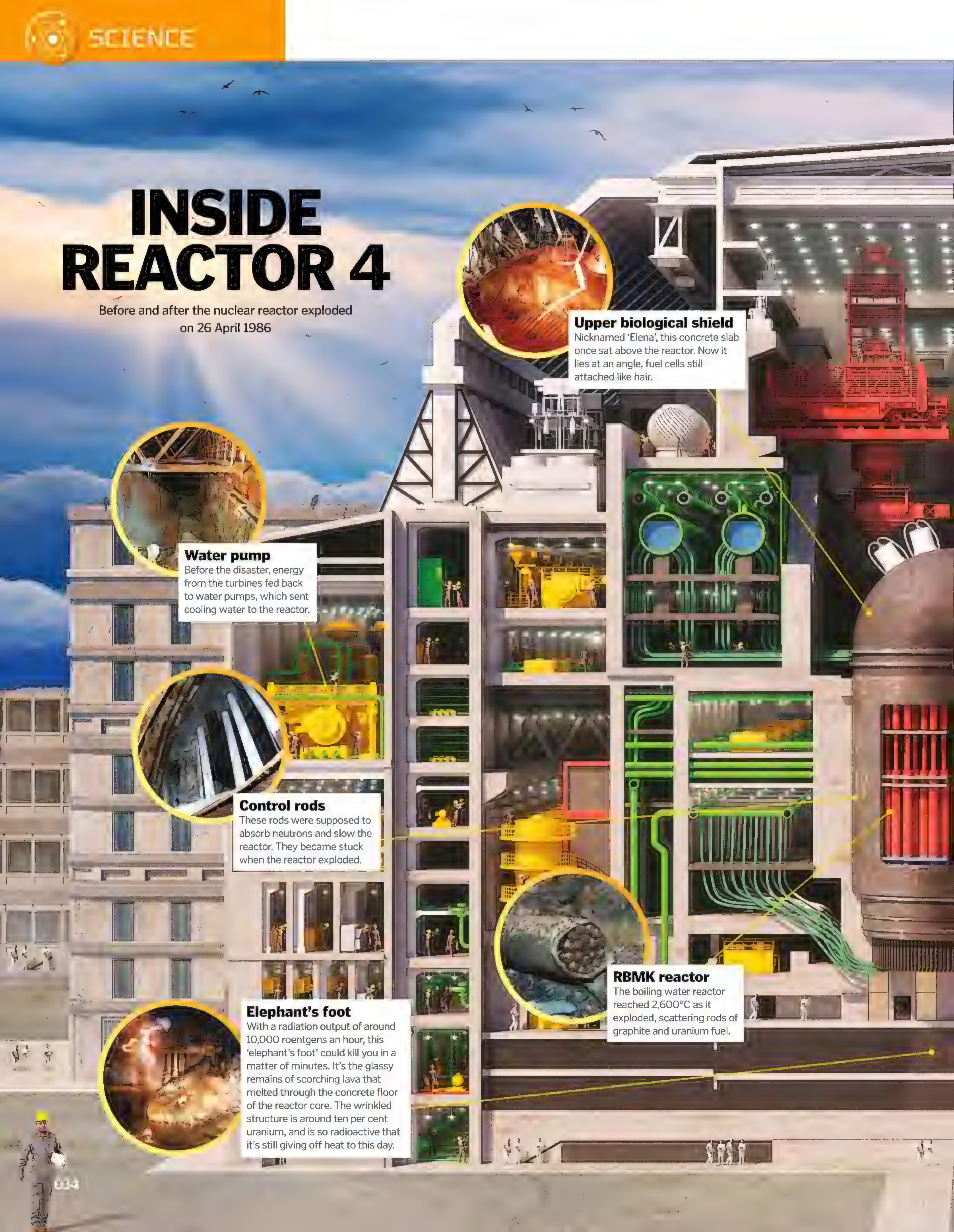
Elephant's foot

With a radiation output of around 10,000 roentgens an hour, this 'elephant's foot' could kill you in a matter of minutes. It's the glassy remains of scorching lava that melted through the concrete floor of the reactor core. The wrinkled structure is around ten per cent uranium, and is so radioactive that it's still giving off heat to this day.



RBMK reactor

The boiling water reactor reached 2,600°C as it exploded, scattering rods of graphite and uranium fuel.

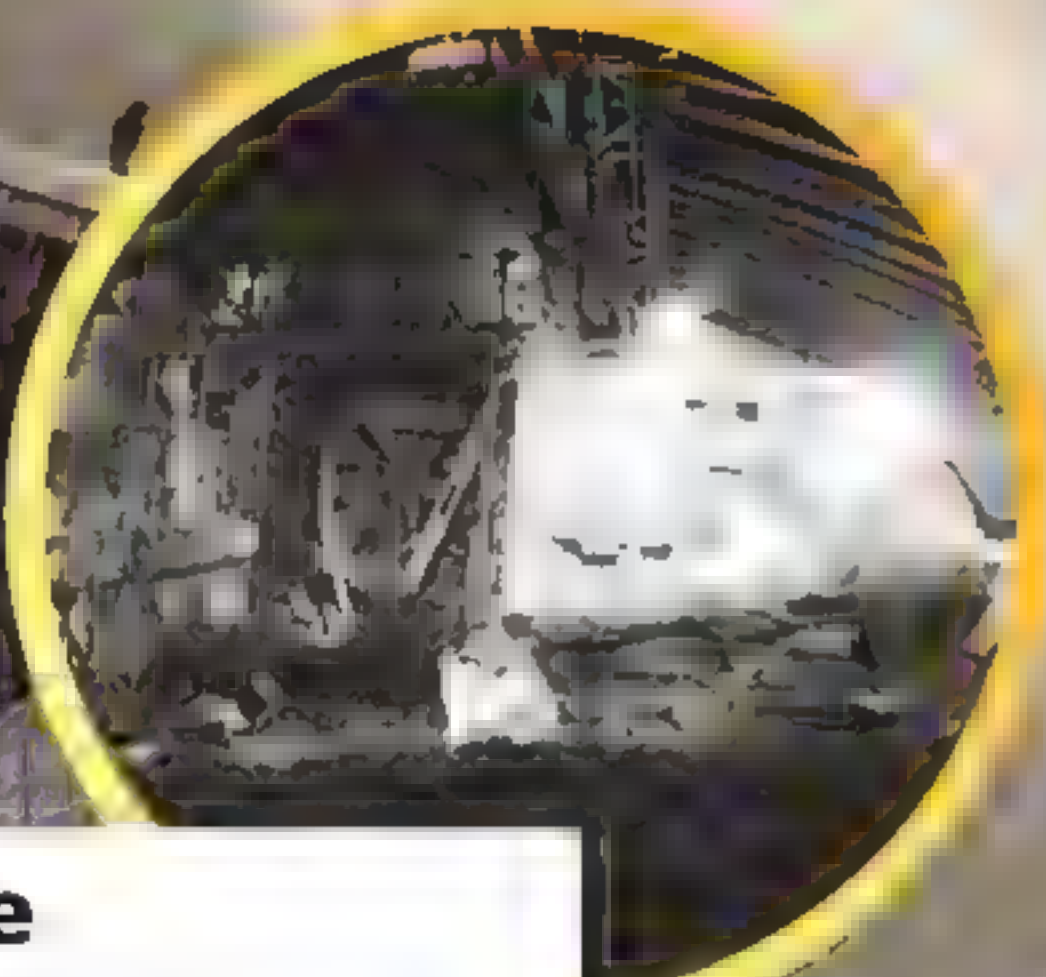




A herd of rare
Przewalski's horses
live in
abandoned



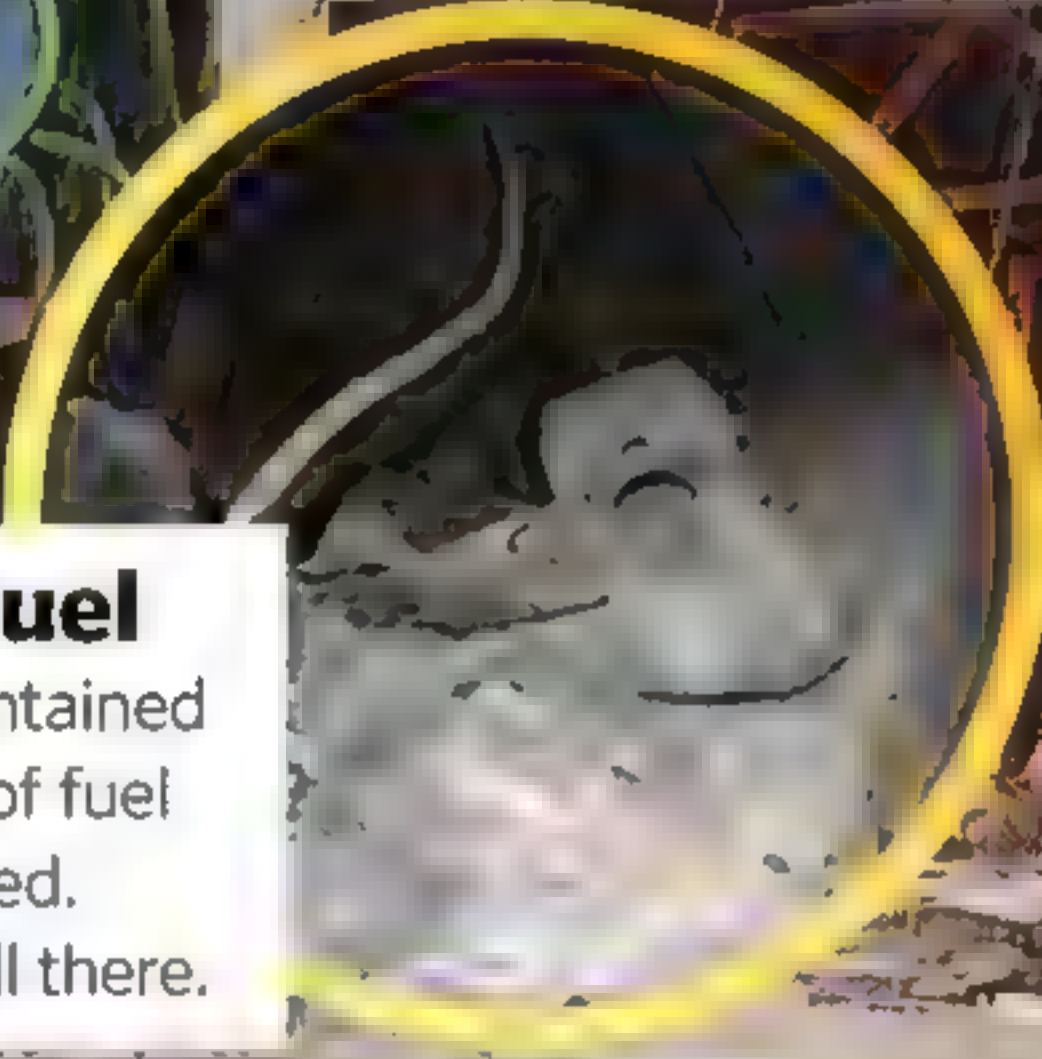
Turbine
The working reactor used steam to drive two 500 MWe turbines, generating power.



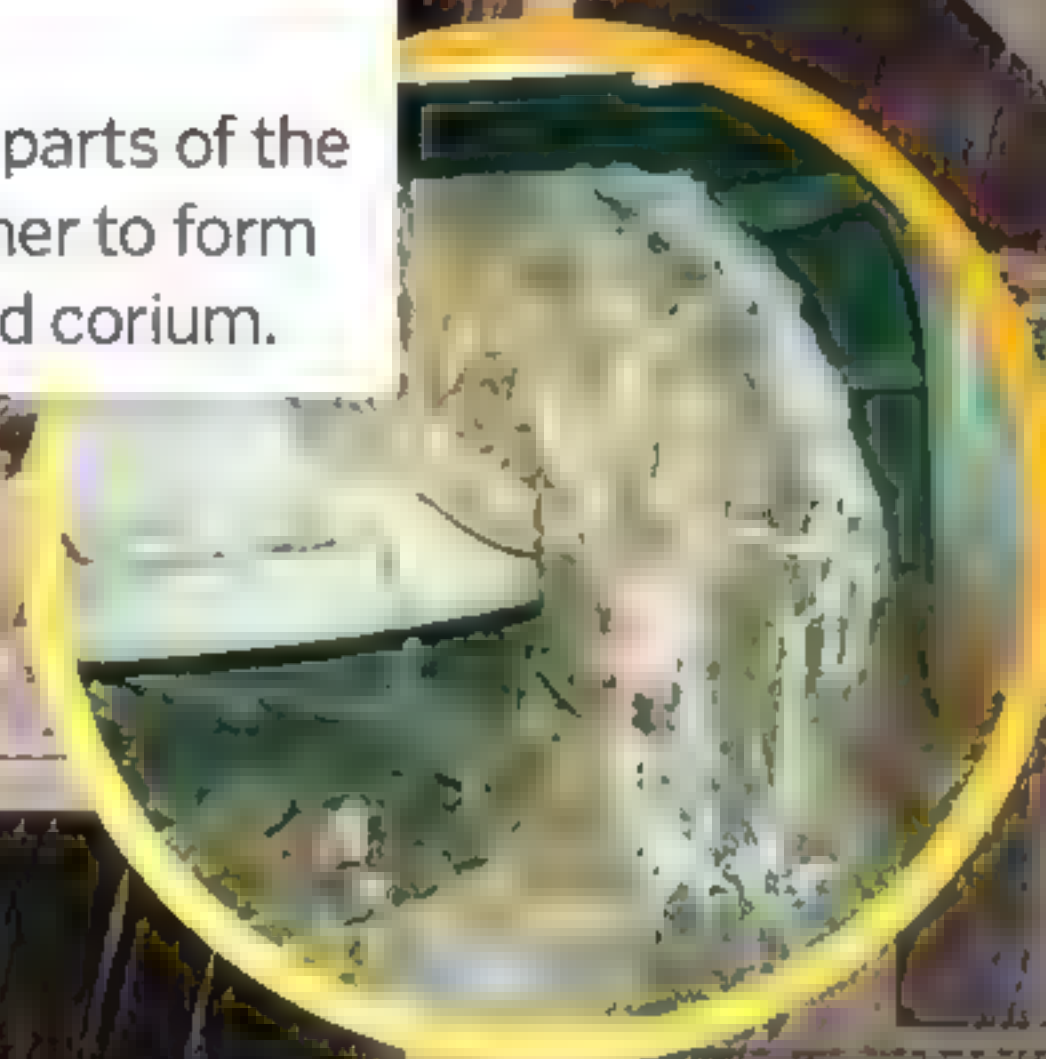
Sand pile
After the explosion, helicopters dropped thousands of tons of sand, clay, lead and boron onto the reactor fire.



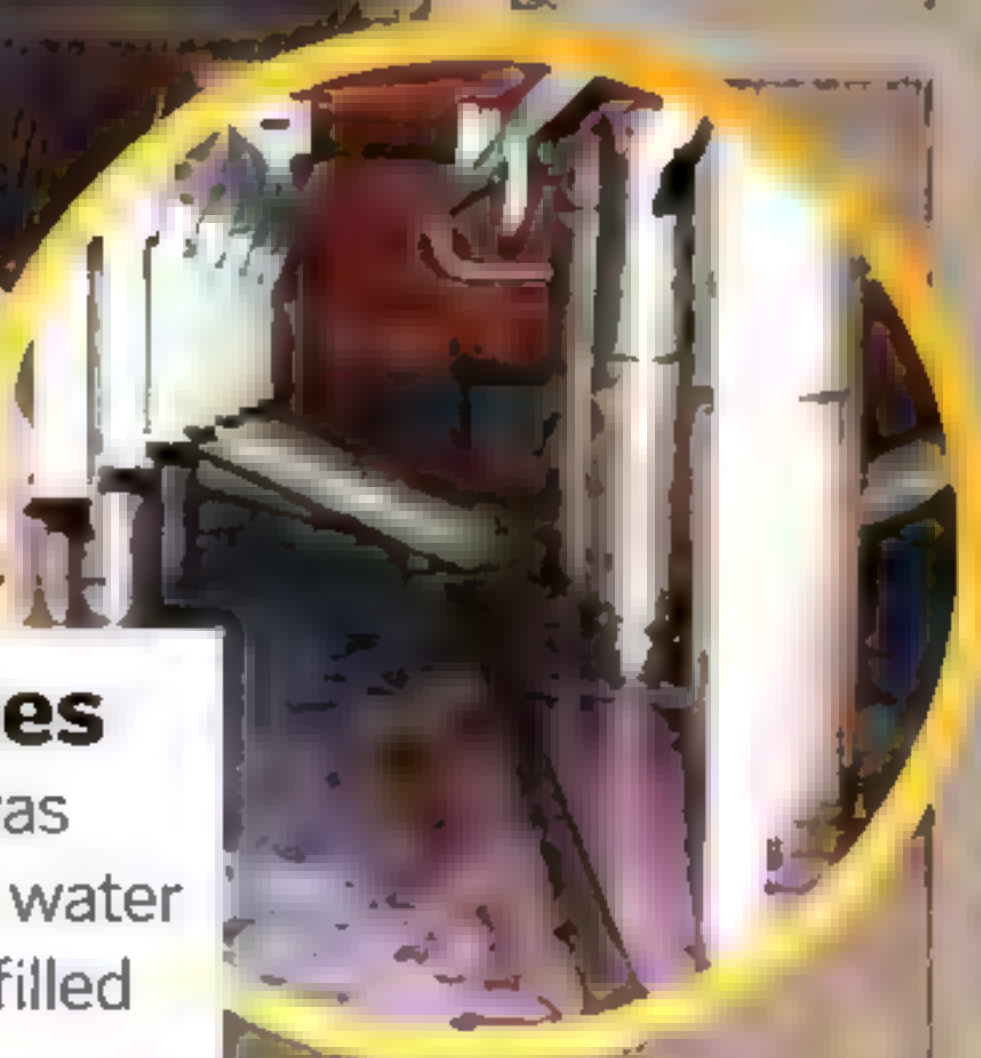
Explosive damage
A steam explosion blew through the building, and hot radioactive debris set fire to the roof.



Leftover fuel
The reactor contained around 200tn of fuel when it exploded. Most of it is still there.



Fuel lava
Fuel, control rods and parts of the building melted together to form radioactive lavas called corium.



Pressure tubes
When the reactor was operational, cooling water moved around fuel-filled pressure tubes.



Radioactive rocks
Five types of lava leaked through the floor of the reactor: brown ceramics, black ceramics, slag, pumice and melted metal.



Enter the forest today and you'll find wild boar, brown bears, elk, roe deer, wolves, lynx and bison. Incredibly, numbers of endangered birds like black storks and white-tailed eagles are higher inside the exclusion zone than anywhere else in Ukraine.

Some areas of the forest are still hot with radiation. Here, animal tracks disappear and birds go quiet. In these regions there are no organisms to break down falling leaves, so the litter on the forest floor is much thicker than it should be. To reduce the risk of fire, a herd of rare Przewalski's horses have been introduced into the zone to graze the forest floor. And, despite the radiation, they seem to be thriving.

With plants and animals flourishing across the exclusion zone, scientists have been working on ways to make the ground safe to farm again. Plants grown on contaminated soil take in caesium particles and aren't yet safe for humans to eat. But researchers have discovered that potassium fertilisers can stop plants taking up radioactive particles. Straw around the base of the plants can then stop radiation getting back into the soil. Even simply ploughing the Earth can help to reduce hot spots by spreading out the radioactive particles. While each method only makes a small difference, combining them together could make the ground safe once again.

As the exclusion zone recovers, one major problem still remains. Reactor 4 is still there,

along with 95 per cent of its radioactive fuel, and the cement sarcophagus built around it in the 1980s is crumbling. If it starts to collapse, it could release fresh clouds of radioactive dust into the air.

To stop this from happening, an international team completed a New Safe Confinement shelter in 2016 to contain the dust in case of collapse. Cranes will painstakingly disassemble the rubble so that the high-level waste can be removed and buried safely. Beneath the shield, radiation levels still reach up to 500 mSv per hour. But outside, life is returning to normal. Standing directly on the new arch is now no more dangerous than having a dental X-ray. Thanks to intensive work over the past 30 years, the Chernobyl exclusion zone is starting to recover.



1,000 'self-settlers' returned to the zone to live on the radioactive land



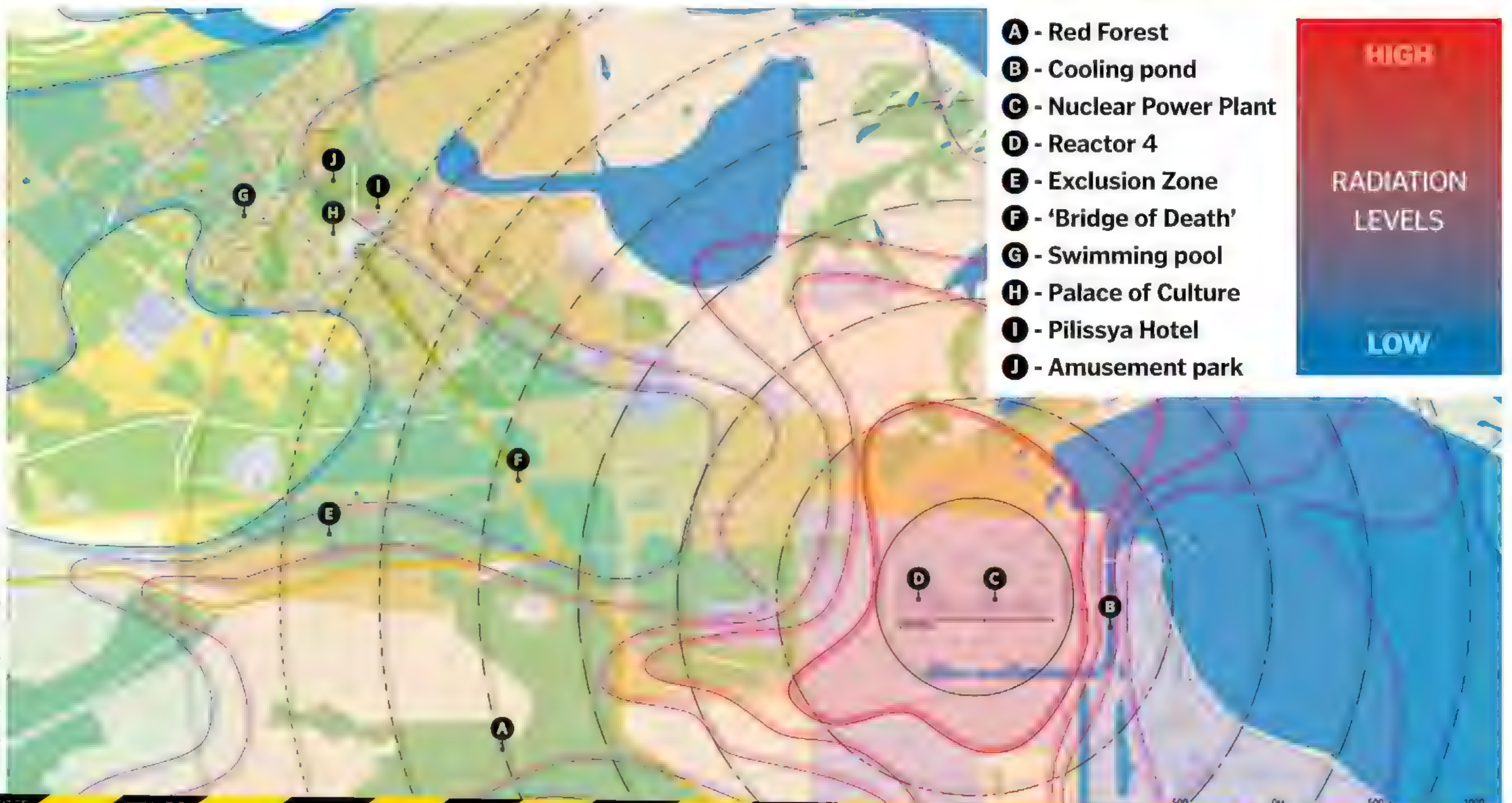
Wolves faced extinction in Europe but they're thriving inside the exclusion zone

Why Chernobyl's wolves thrive

Forests still have some of the highest contamination of any ecosystem inside the exclusion zone. But that hasn't deterred the local wildlife. Some of Europe's most elusive mammals have made their homes between the trees, and they seem to be thriving. It appears European grey wolves would rather face low-level radiation than risk living alongside humans. There are now seven times more wolves inside the zone than in protected areas nearby. Without us to interfere, they are free to chase deer, catch fish and even eat fruit from abandoned orchard trees. In fact, conditions are so good that scientists have spotted young males leaving the exclusion zone in search of more room.

Exclusion zone radiation

This heat map reveals radiation levels inside the Chernobyl exclusion zone today

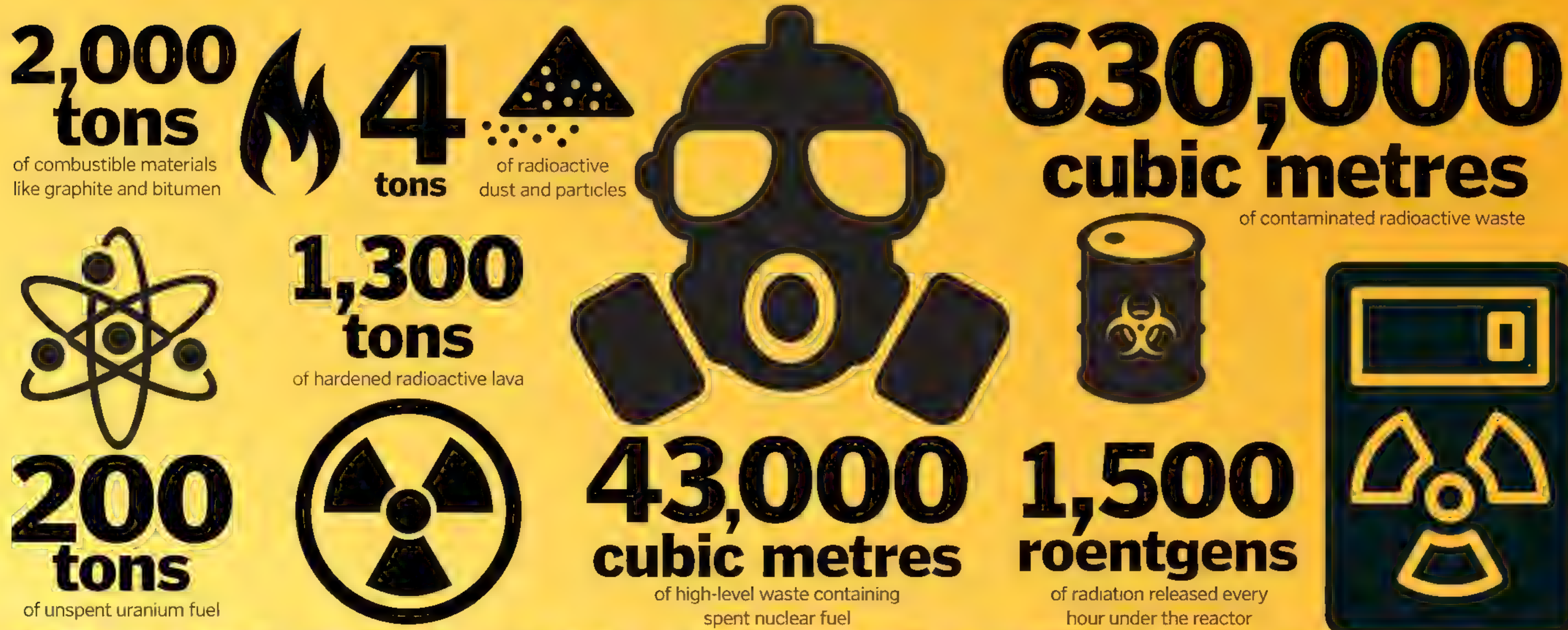


DID YOU KNOW? There are around 450 nuclear reactors worldwide, supplying roughly 11 per cent of our electricity



WHAT REMAINS?

The disaster has had a lasting effect on the surrounding area



© Getty Illustration by Ed Crooks

ATOM ANATOMY

The structure of these microscopic building blocks drives the chemistry of the universe

Words by Laura Mears

Atoms are the building blocks of everything around you, from the cells in your body to the cup of tea in your hand. Made from elementary particles and held together by fundamental forces, they drive the chemistry of the universe.

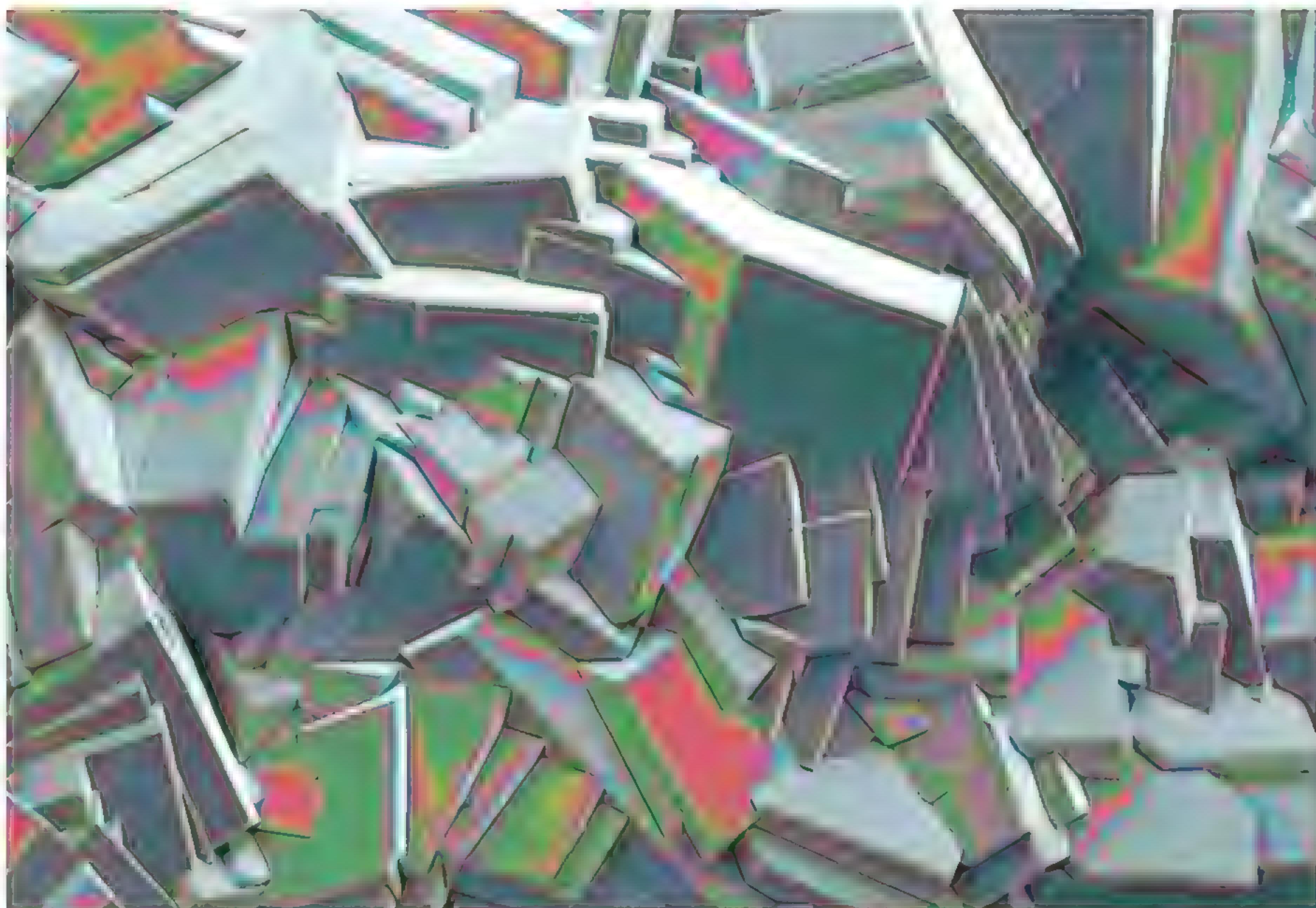
Each one has a tiny, positively charged nucleus, balanced by a cloud of negatively charged electrons. These determine the atom's properties. Split an atomic nucleus open and you'll find subatomic particles called protons and neutrons. The simplest atom, hydrogen, has just one proton and no neutrons. But as you move up through the periodic table the number of protons rises one by one. With each extra proton, the behaviour of the atom changes.

Protons have a positive charge, so for every extra one added the atom also gains another

negative electron. These electrons cluster in fixed zones around the atomic nucleus, known as orbitals or shells. Each shell can only hold a certain number of electrons. So when a shell fills up, the next electrons have to start a new one.

Atoms are most stable when their electron shells are full, but most elements have electrons to spare. This is the driving force behind the chemistry we see around us. To complete half-filled shells, atoms form chemical bonds. They can either share their electrons to form

"Split an atomic nucleus open and you'll find subatomic particles"



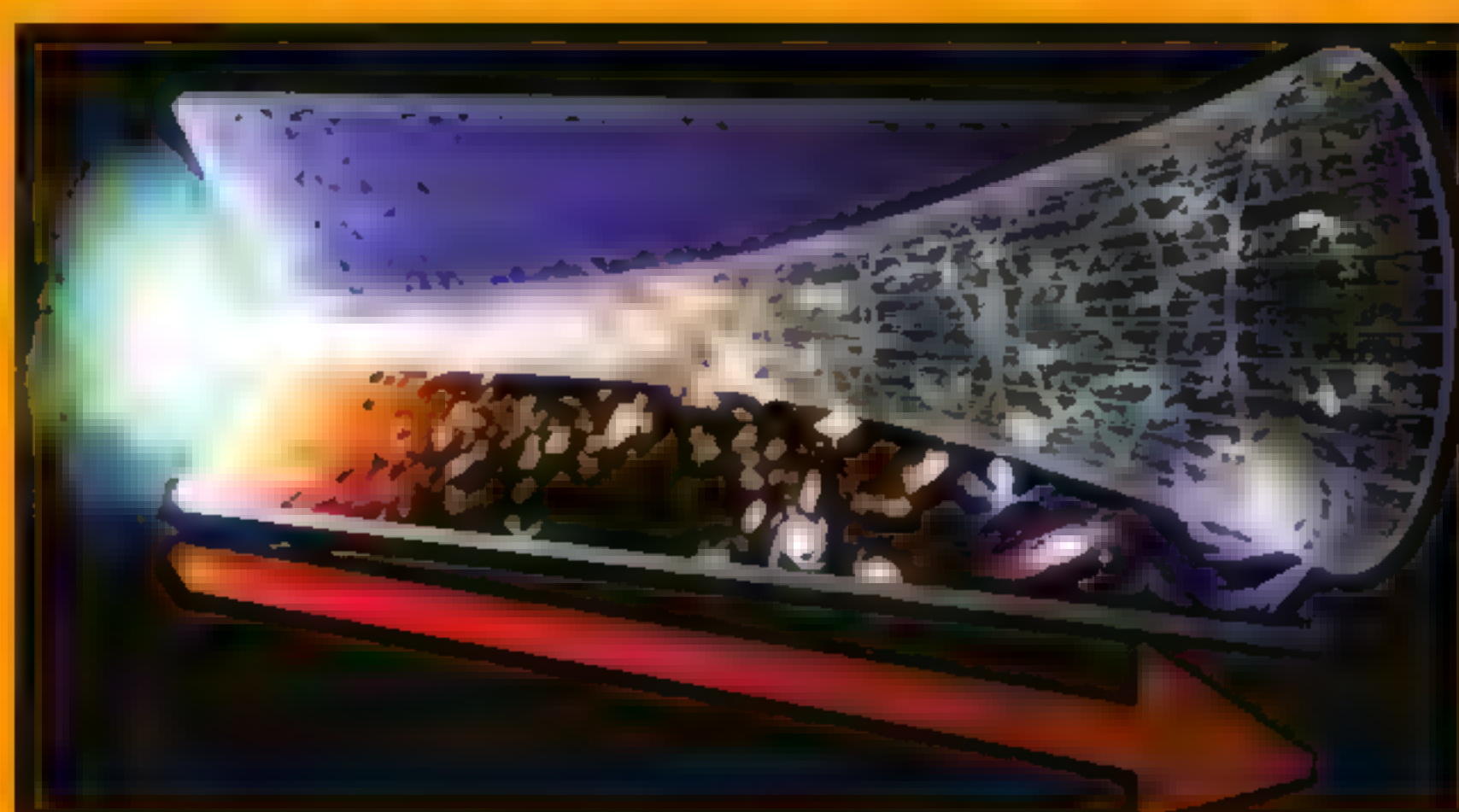
These are sugar crystals magnified 1,250 times by a scanning electron microscope

The birth of atoms

13.8 billion years ago the big bang created the universe. In the first moments it was too hot and dense for any particles could survive. Whenever positrons and electrons burst into existence, they immediately broke apart. But as the universe expanded and started to cool, these elementary particles became more stable. Their quarks started to come together in fermions and bosons. Within minutes, these were combining to form the first atomic nuclei.

It took another 380,000 years for the universe to cool enough to allow complete hydrogen atoms to form, and then for the magic started to happen. Gravity started to pull the atoms into clumps, and as these clumps grew the pressure inside started to build. The atomic nuclei got so close

together that they started to fuse, and the first stars were born. The stars that formed billions of years ago from atoms made from the big bang, creating all the elements we see around us today.



Hydrogen atoms fused together to form helium, and the energy that was released



Different elements can combine together to make complicated compounds



MIXTURE

Your cup of tea is a mixture; a combination of different molecules and compounds not linked by chemical bonds. It contains water, as well as the molecules from the tea itself: polyphenols, amino acids, enzymes, pigments, volatiles and caffeine. Perhaps milk is there too, which contains fats, proteins and sugars. And maybe also table sugar.

Scale: 10 centimetres

COMPOUND

If you stuck a powerful microscope into your tea, you'd start to see the compounds that make up the mixture.

Compounds are substances made from two or more different elements bonded together. Caffeine has the chemical formula $C_8H_{10}N_4O_2$. It contains eight carbon atoms, ten hydrogen, four nitrogen and two oxygen.

Scale: 0.75 micrometres

MOLECULE

Break caffeine into pieces and you'd end up with molecules.

These contain just one type of atom and are the smallest units that can take part in chemical reactions. If you broke the caffeine compound up, its oxygen atoms would pair together, forming an oxygen molecule with two identical atoms.

Scale: 211 picometres

ELEMENT

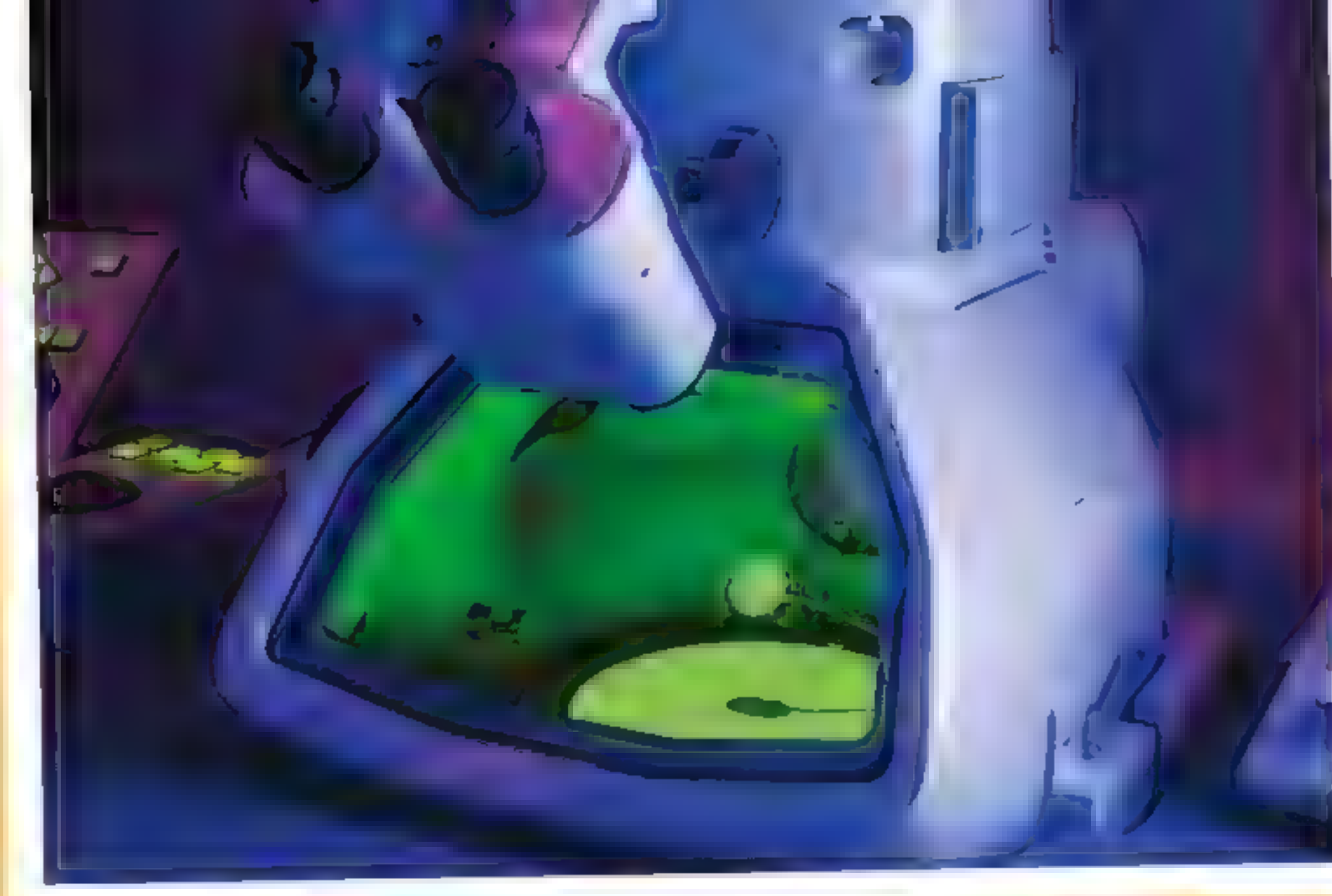
Zoom in on an oxygen molecule and you'd see the individual oxygen element. Elements are substances that contain only one type of atom. There are over 90 naturally occurring elements on Earth, and even more made synthetically in laboratories. Oxygen is element number 8.

Scale: 60 picometres

ATOM

One final zoom would reveal the subatomic particles inside the atoms: positive protons, neutral neutrons and negative electrons. The numbers of each give different elements their distinctive chemical properties. An oxygen atom contains eight protons, eight neutrons and eight electrons.

Scale: 1 femtometre



The highest-resolution electron microscopes can zoom in on single atoms

Anatomy of an atom

Lifting the lid on the subatomic particles that make up the atoms in the air we breathe

Electron

These subatomic particles have a mass of almost zero and a charge of -1.

Proton

These subatomic particles have a mass of 1 and a charge of +1.

Neutron

These subatomic particles have a mass of 1 and a charge of 0.

Nucleus

The atomic nucleus of an oxygen atom contains eight protons and eight neutrons.

Shells

An oxygen atom contains eight electrons, arranged into two orbital shells.

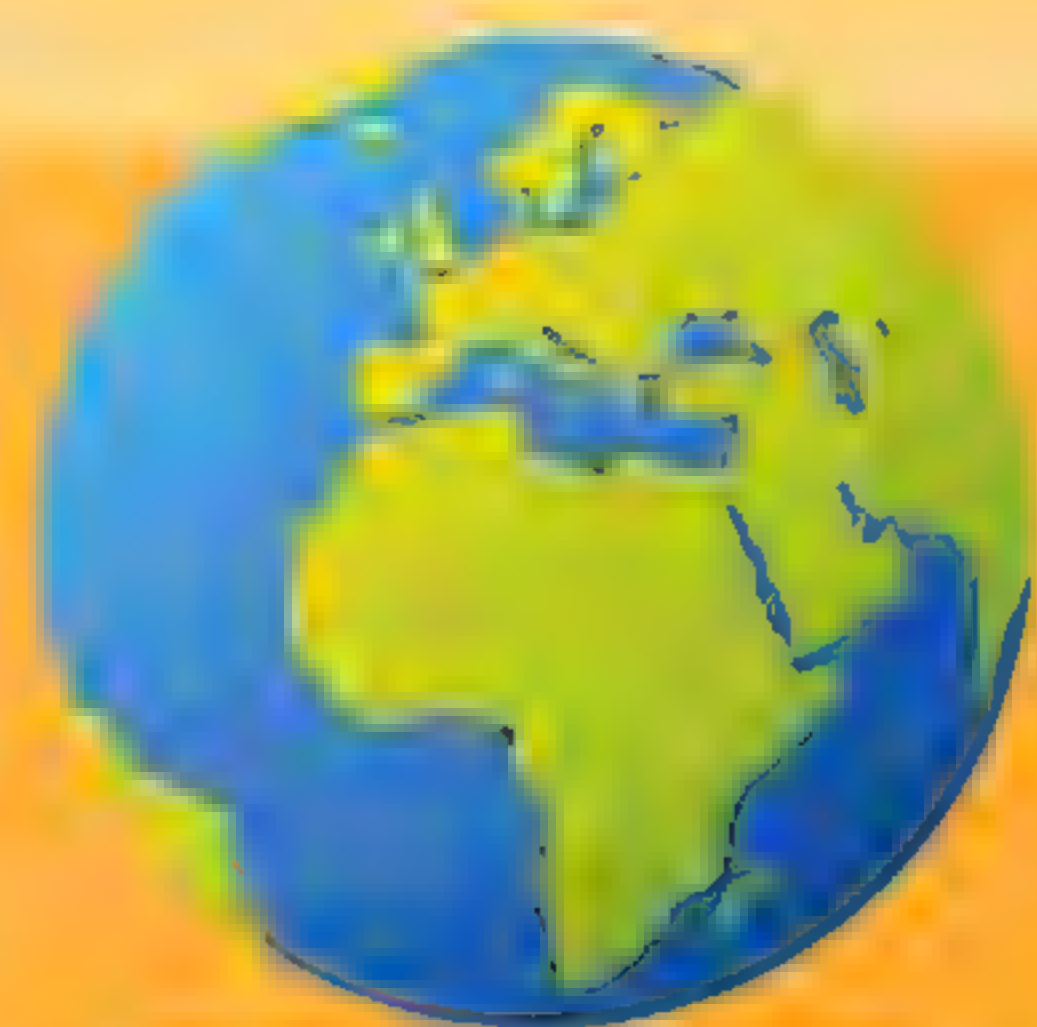
Unpaired electrons

Two electrons in the outer shell don't have a partner. This allows oxygen atoms to form chemical bonds.

ATOM FACTS

118

Number of elements in the periodic table



90

Number of elements that are stable

of the 118 elements

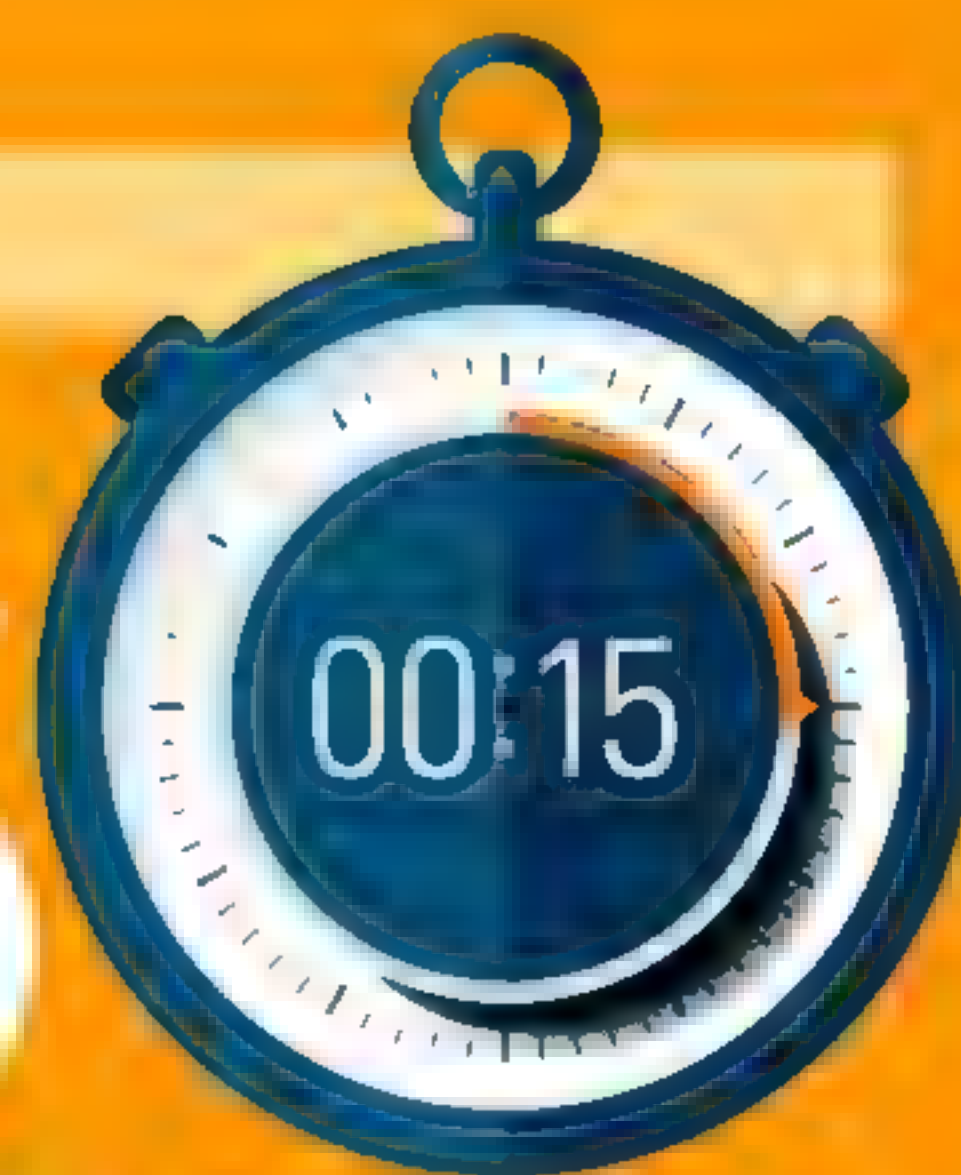
75%

Most of the matter in the universe is hydrogen



2.6 secs

The number of chemicals currently in use in industry



50 million

Chemical compounds that have been discovered

7,700



Stars made all of the elements heavier than hydrogen and helium

covalent bonds, or they can steal electrons from one another to form ionic bonds.

Covalent bonds are common inside our own bodies. Carbon atoms need four electrons to complete their outer shell, so they share with up to four other atoms, including other carbons. This makes them perfect for forming large biological molecules like DNA.

Ionic bonds are more commonly found in the ground. They happen when a non-metal steals electrons from a metal, becoming negatively charged. At the same time, the metal becomes positively charged. These ions attract one another, sticking together in repeating structures, like salt crystals.

“They can share their electrons to form covalent bonds, or they can steal electrons”

Bonds between atoms can break and reform, allowing the elements to perform some amazing chemical tricks. They combine to produce larger compounds, decompose to form smaller ones, or swap one element for another to produce a chemical with different properties. These dynamic interactions are happening all around us, all the time.

Smaller still

The protons and neutrons that make up the atomic nucleus aren't the smallest components of matter. These are the 'elementary particles' – quarks and leptons. There are six types of quark, arranged into pairs: up and down, charm and strange, top and bottom. They have a partial electrical charge and a 'colour' charge of red, green or blue. There are also six types of lepton: electron, muon, tau and their associated neutrinos. If taking these particles to make up the simplest hydrogen atom, you use quarks and one down quark for the positive and one electron to orbit around the outside. The most common form of hydrogen has no neutrons.

LEPTONS

UP	1/3	DOWN	2/3
CHARM	2/3	STRANGE	1/3
TOP	2/3	BOTTOM	1/3
NEUTRINO	0	ANTINEUTRINO	0

QUARKS

UP	2/3	DOWN	1/3
CHARM	2/3	STRANGE	1/3
TOP	2/3	BOTTOM	1/3
NEUTRINO	0	ANTINEUTRINO	0

Quarks and leptons are the smallest particles known to exist.

Atomic evolution

Our understanding of atomic structure has come a long way in the past 200 years

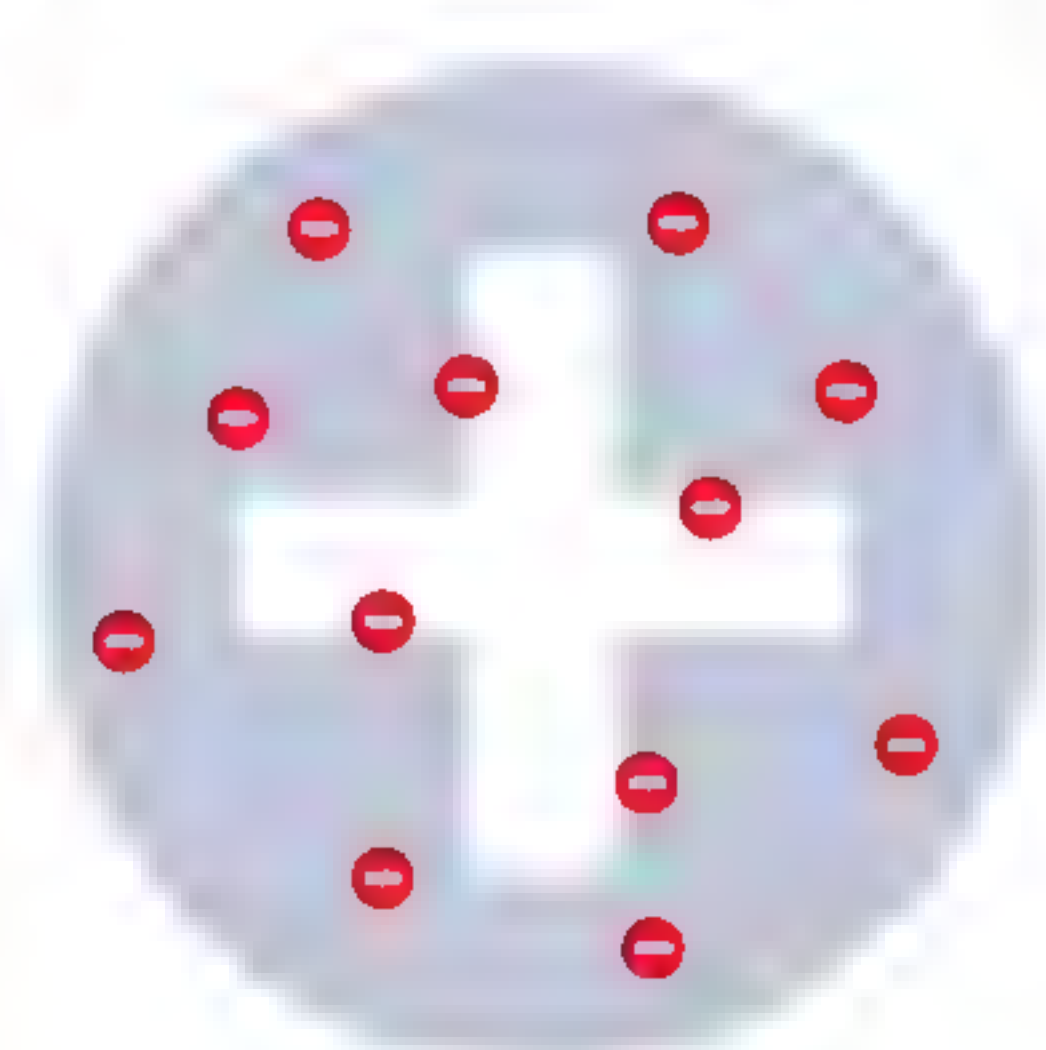


1803 Solid sphere

John Dalton was the first to describe atoms. The word came from the ancient Greek 'a', meaning 'not', and 'temnein', meaning 'to cut'. He thought that they were indivisible.

ACCURACY

Dalton recognised that different types of atom had different properties. But he didn't realise they contained smaller subatomic particles.



1894 Plum pudding

J.J. Thomson discovered electrons and made a new model of the atom to include them. He stuck them inside a sphere of positive charge, like fruits in a cake.

ACCURACY

This model recognised that atoms contained smaller components, including electrons. But the structure was wrong; the atomic nucleus was missing.

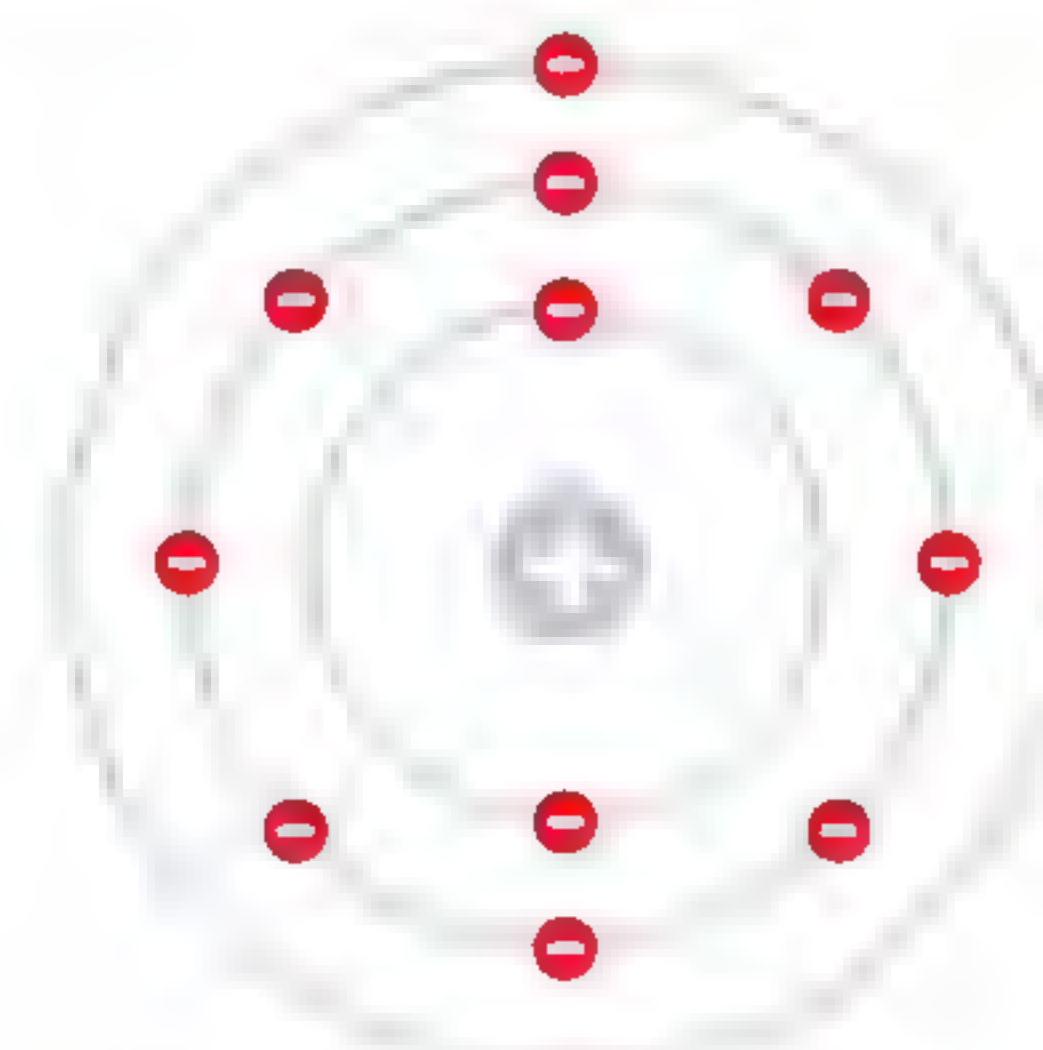


1911 Nuclear

When Ernest Rutherford tried firing tiny particles at atoms, most passed through. This revealed that most of the atom is empty space, with a small nucleus at the centre.

ACCURACY

A positive nucleus surrounded by negative electrons is close to our modern understanding of atoms. But Rutherford hadn't quite captured how electrons move.



1913 Planetary

Niels Bohr's planetary model describes electrons travelling in orbits called 'shells'. They are a fixed distance from the nucleus and have a fixed energy level.

ACCURACY

The planetary model explains why small elements absorb and emit certain frequencies of radiation. However, it runs into problems as elements get heavier.



1926 Quantum

Rather than think of orbitals as circular paths, Erwin Schrödinger imagined them as probability clouds. There is a 90 per cent chance of finding an electron somewhere inside its orbital.

ACCURACY

This model is the most up to date. Thinking of electrons as waves in clouds of probability helps to explain the behaviour of subatomic particles.



ENVIRONMENT

044 Life at the extreme

The beings that call the harshest habitats home

052 The foam-nest frog

How do these hoppers build with foam?

054 Deadly plants

They look harmless, but these plants are lethal

058 The Rainbow Mountain

Scale the heights of Peru's magic mountain

059 How coral reefs form

The process that builds these vital marine havens

060 Animal antidotes

Venom won't deter these unique creatures

064 Trees of life

How oak trees support their ecosystems



052
The
foam-nest frog



054
Deadly
plants



058
Rainbow
Mountain



044

Life at
the extreme



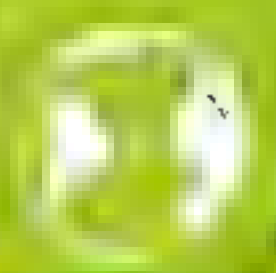
060

Animal
antidotes



064

Trees of life



LIFE AT THE

EXTREME

From volcanic ocean vents to the tops of the Himalayas, extremophiles have found ways to conquer every corner of the planet

Words by **Victoria Williams**

Although a few organisms with staggering survival skills have been known to us for centuries, the term 'extremophile' was first coined in 1974 by a scientist called R D MacElroy. It means 'extreme-loving' and refers to any form of life that thrives outside the narrow band of conditions humans can tolerate. Extremophiles have only been studied in detail for the last few decades, but they've already challenged many ideas we have about life and its limits.

Most extremophiles belong to the domain Archaea. These organisms consist of a single cell without a nucleus, and they're believed to be the oldest life forms on Earth, dating back billions of years. It's little surprise that these ancient species are the most tolerant and adaptable, since the young planet would have been a volatile and extreme place enveloped by a toxic atmosphere.

Today, extremophiles can be found all over the world in the most inhospitable environments; even the most desolate landscape is likely to be teeming with life invisible to the naked eye.

THERMOPHILES

In pools and springs hot enough to cause severe burns and even death to humans you'll find thermophiles feeding on the sulphur and ammonia in the blistering water. These microbes often produce pigments and lend their bright colours to the edge of the water. Heat-loving organisms have fatty acid linings in their cell membranes to stop them disintegrating at high temperatures.

At the bottom of the ocean, vents known as black smokers send out plumes of water and minerals reaching 400 degrees Celsius in temperature. The liquid doesn't boil because of the immense pressure it's under from the water above, but it still seems like the last place creatures would choose to live. Amazingly, it's not just microorganisms that can bear to be around these cracks in the

"An extremophile is any form of life that thrives outside the narrow band of conditions humans can tolerate"



Earth's surface; busy ecosystems develop and flourish around them, sustained by the nutrients leaking out from the planet's crust. Bacteria are the first to track down a new vent, followed by hardy bivalves like clams. Larger creatures like tubeworms and lobsters move in later, creating unusual communities that have amazed scientists since they were discovered in the 1970s.

CRYOPHILES

Frigid water, permafrost, mountain peaks and expanses of ice are havens for cryophiles. These organisms live in parts of the world that remain permanently cold and can withstand temperatures well below freezing, with some unicellular species still active at -25 degrees Celsius. Cryophiles, ranging from bacteria to deepwater fish, often produce antifreeze proteins to prevent ice crystals from forming in their bodily fluids.

As well as the freezing temperatures, cryophiles must contend with other stresses like high pressure and low oxygen levels on the seabed and high salinity in sea ice. When times get really tough, some cold-dwellers shut down their bodies and enter a state of dormancy until conditions become more tolerable again.

ACIDOPHILES AND ALKALIPHILES

While humans are best suited to a neutral pH

between 6.5 and 7.5, acidophiles flourish in acidic environments where the pH is 5 or lower. Strong cell membranes keep them safe from the potentially damaging effects of acid, allowing them to live in sulphuric pools, polluted water and even human stomachs. Some aggregate for extra protection, forming slimy colonies called biofilms.

Alkaline conditions, at the other end of the scale, can be just as challenging. Alkaliphiles like *Spirochaeta americana* – bacteria found

Extreme enzymes

Enzymes are protein molecules that act as catalysts for chemical reactions in the body, and they're vital for keeping processes running smoothly. Most enzymes lose their structure and stop functioning – a process known as denaturing – when they reach the limits of their optimal ranges of temperature, salinity and pH. Extremophiles, however, have specialised enzymes, known as extremozymes, which are as well adapted to extreme environments as they are. For example, thermophile enzymes are compact, with a tightly wound structure to ensure they hold their shape under the effects of high temperature.

Extremozymes have been harnessed for use in industrial processes. While most

"Busy hydrothermal ecosystems are sustained by the nutrients leaking out from the planet's crust"



Industrial enzymes have become big business

enzymes can't cope with the harsh conditions, those derived from extremophiles work well and catalyse reactions to make the processes more efficient. Used in the manufacture of products from food to fuel, the global market for industrial enzymes has rapidly grown to billions of dollars.

Yellowstone National Park, US

Over half of the world's hot springs and geysers are in Yellowstone – paradise for thermophiles.

Atacama Desert, Chile

Bacteria have been found living among soil particles in the planet's driest desert.

Earth's most extreme environments

Lake Retba, Senegal

This lake gets its famous pink colour from an algae species that thrives in its extremely salty water.

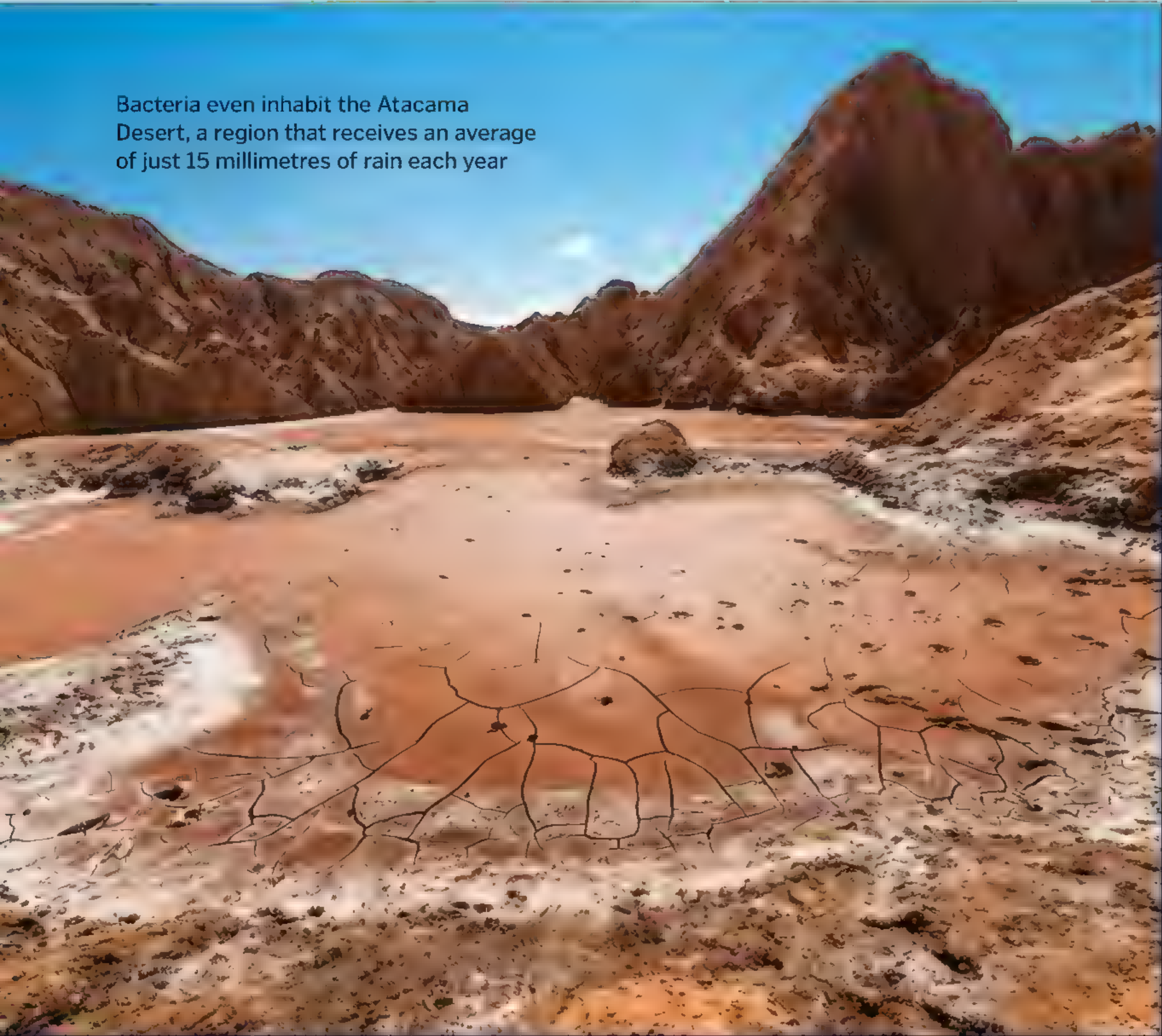
Antarctic ice sheet

Cold-loving organisms inhabit the tiny water-filled cracks in Antarctica's vast ice sheet.

Mount Everest, Himalayas

With freezing temperatures and a thin atmosphere, Everest is a challenging home for the spider *Euophrys omnisuperstes*.

Bacteria even inhabit the Atacama Desert, a region that receives an average of just 15 millimetres of rain each year



The bright colours of Yellowstone's Morning Glory Pool are also the result of bacteria

Ring of fire

This outer orange ring is home to chloroflexi bacteria and *Synechococcus*, with both managing to get by in 65°C.

The Grand Prismatic Spring

The striking colours in Yellowstone's largest geyser are produced by different species of thermophile

Clear blue

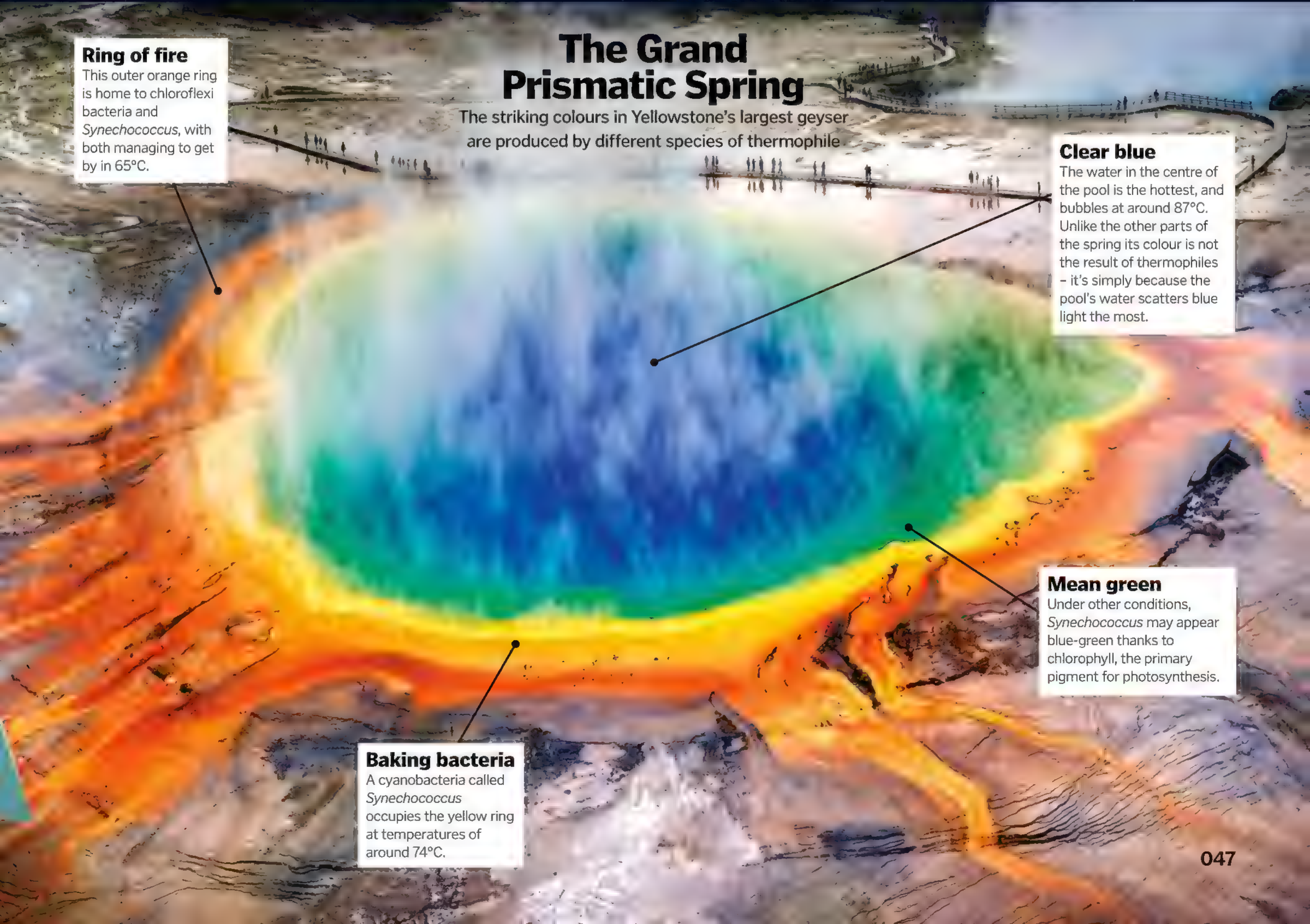
The water in the centre of the pool is the hottest, and bubbles at around 87°C. Unlike the other parts of the spring its colour is not the result of thermophiles – it's simply because the pool's water scatters blue light the most.

Mean green

Under other conditions, *Synechococcus* may appear blue-green thanks to chlorophyll, the primary pigment for photosynthesis.

Baking bacteria

A cyanobacteria called *Synechococcus* occupies the yellow ring at temperatures of around 74°C.





The soda cichlid swims happily in the alkaline waters of a soda lake

In salty, mineral-rich mud deposits at Mono Lake in California – cannot survive at a pH lower than 8 and do not need oxygen to respire. By actively driving certain molecules out of their cells in exchange for others, they can produce an internal pH closer to neutral than their surroundings and avoid any damage to their structure.

METHANOGENS

Methanogens are microorganisms that produce methane as a byproduct when their metabolic processes take place in low oxygen levels. Living in oxygen-poor swamps and marshes, they're responsible for the bubbling that can be seen at the surface. Most people know that cows produce levels of methane

harmful to the environment, but it's a lesser-known fact that the blame for this gas really lies with methanogens inhabiting the animals' guts.

Methane-emitting organisms have been found under kilometres of ice and in desert soil. The discovery of methanogens in arid environments is of particular interest to scientists; some believe that methane detected in the atmosphere around Mars could be a sign of microorganisms living on the Red Planet.

POLYEXTREMOPHILES

Few things in nature are simple or fit into neat categories, and there are extremophiles that require an even longer title than the others because they're adapted to live with multiple stressors. Take *Desulforudis audaxviator*; this bacteria lives 2.8 kilometres underground in groundwater in a South African gold mine, where it survives on chemicals released by the decay of minerals

Tiny eyes

Tardigrades sense their environment with small, five-cell eyespots and sensitive filaments called cirri.

Salivary gland

Brain

In-built straw

A sucking pharynx extracts fluid from food and sends it to the simple digestive system.

Piercing mouthparts

Sharp structures called stylets in the tubular mouth pierce invertebrates, plants cells and algae during feeding.

Inspiring space exploration

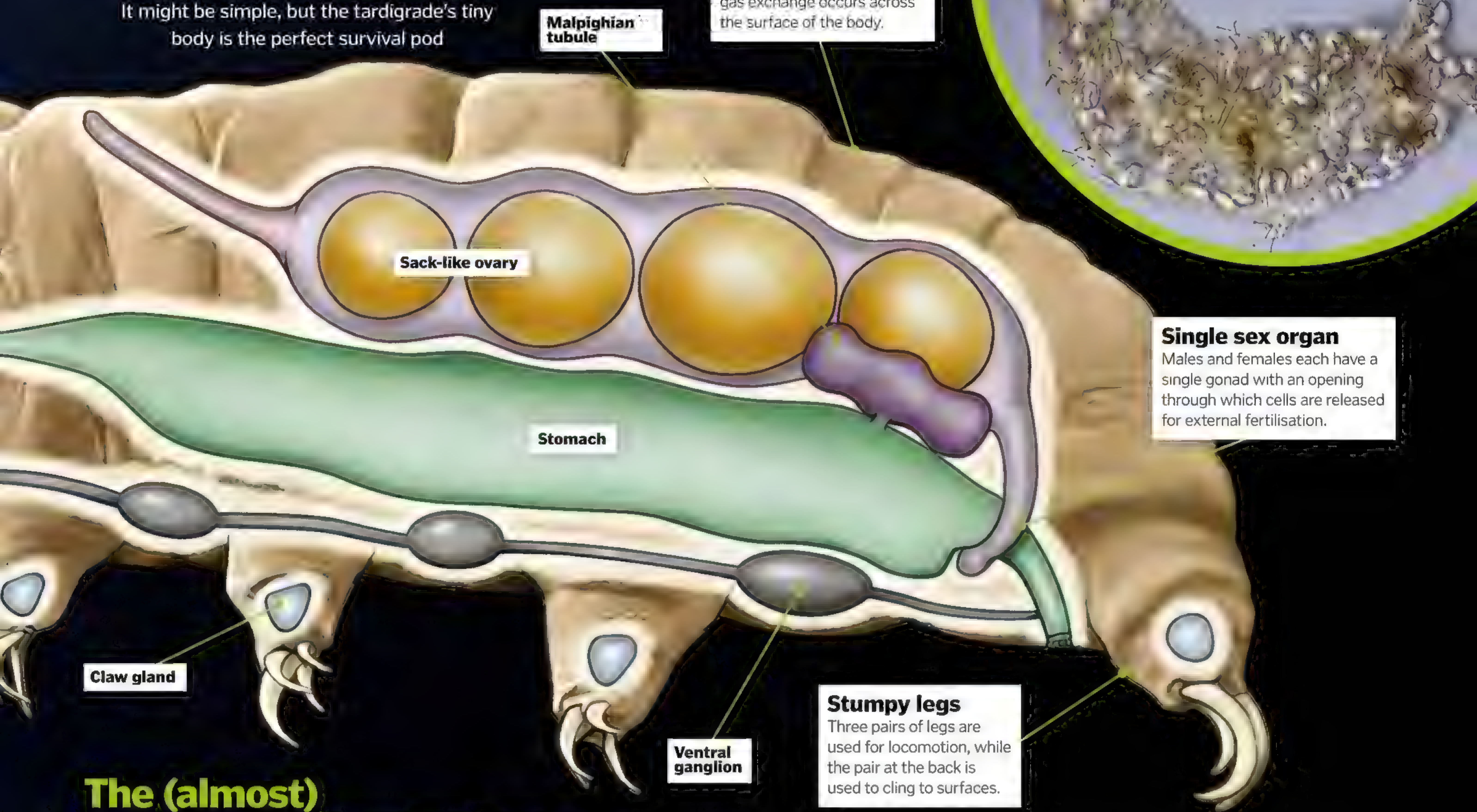
For hundreds of years humans have been debating the possibility of extraterrestrials, and more recently we've started looking for signs of life on other planets. Extremophiles – especially those able to live with more than one extreme factor in their environment – live in parts of the planet most like the harsh landscapes found elsewhere in the galaxy and give scientists an idea of what extraterrestrial organisms might look. The study of Earth's toughest deepwater creatures to help predict what we might one day meet in a dark corner of space was even the focus of a James Cameron film called *Aliens of the Deep*.

Species of extremophile have been discovered in dark and oxygen-deprived subterranean ecosystems in recent years, expanding the area of a Solar System that we might find life elsewhere. This is widening the search for proof that we're not alone in the universe.



Built for survival

It might be simple, but the tardigrade's tiny body is the perfect survival pod



The (almost) indestructible water bear

Tardigrades, microscopic water-dwelling animals also known as water bears, are among the most famous survivalists in the world. Since they were first described by a German zoologist in 1773 they've been found in the depths of the ocean, at the top of Himalayan mountains, at the poles and in hot springs.

Despite this amazing resilience, they're technically not extremophiles. This classification is reserved for those creatures that exploit and thrive in extreme conditions, while tardigrades cope by suspending their metabolism and entering dormancy. During periods of drought, water content in the body drops to one per cent of the normal level. To prevent damage to the body, unique proteins take the place of lost water in the cells and become glass-like. In their dehydrated tun state some species of tardigrade are capable of enduring temperatures close to absolute zero and, though hot temperatures will eventually kill them, they can last for several minutes at 150 degrees Celsius.

With their metabolism barely functioning, starvation can be endured for years. They can also survive radiation levels hundreds of times

higher than the dose that would kill a human and have even returned alive from a journey to the vacuum of space.

Many tardigrades can survive in this desiccated dormant state (known as cryptobiosis) for five years and will resume

normal activity within hours of exposure to moisture. A few exceptional specimens have been 'brought back to life' after almost a decade, establishing tardigrades as some of the creatures most likely to survive a nuclear war or apocalyptic astrophysical event.

Anoxybiosis

When there's no oxygen available, the tiny organism takes on water, becomes swollen and suspends its activity.

Active state

Under the right conditions, tardigrades can move around, grow, eat and reproduce.

Encystment

Under stress, a tardigrade builds up several protective layers of cuticle and becomes dormant.

Tun state

In extreme conditions tardigrades retract their heads and legs, pause their metabolism and allow themselves to dry out.

Anoxybiosis



Response to lack of oxygen

Active



Encystment



Cryobiosis



Response to low temperature

Anhydrobiosis



Response to lack of water

Osmobiosis



Response to high salinity



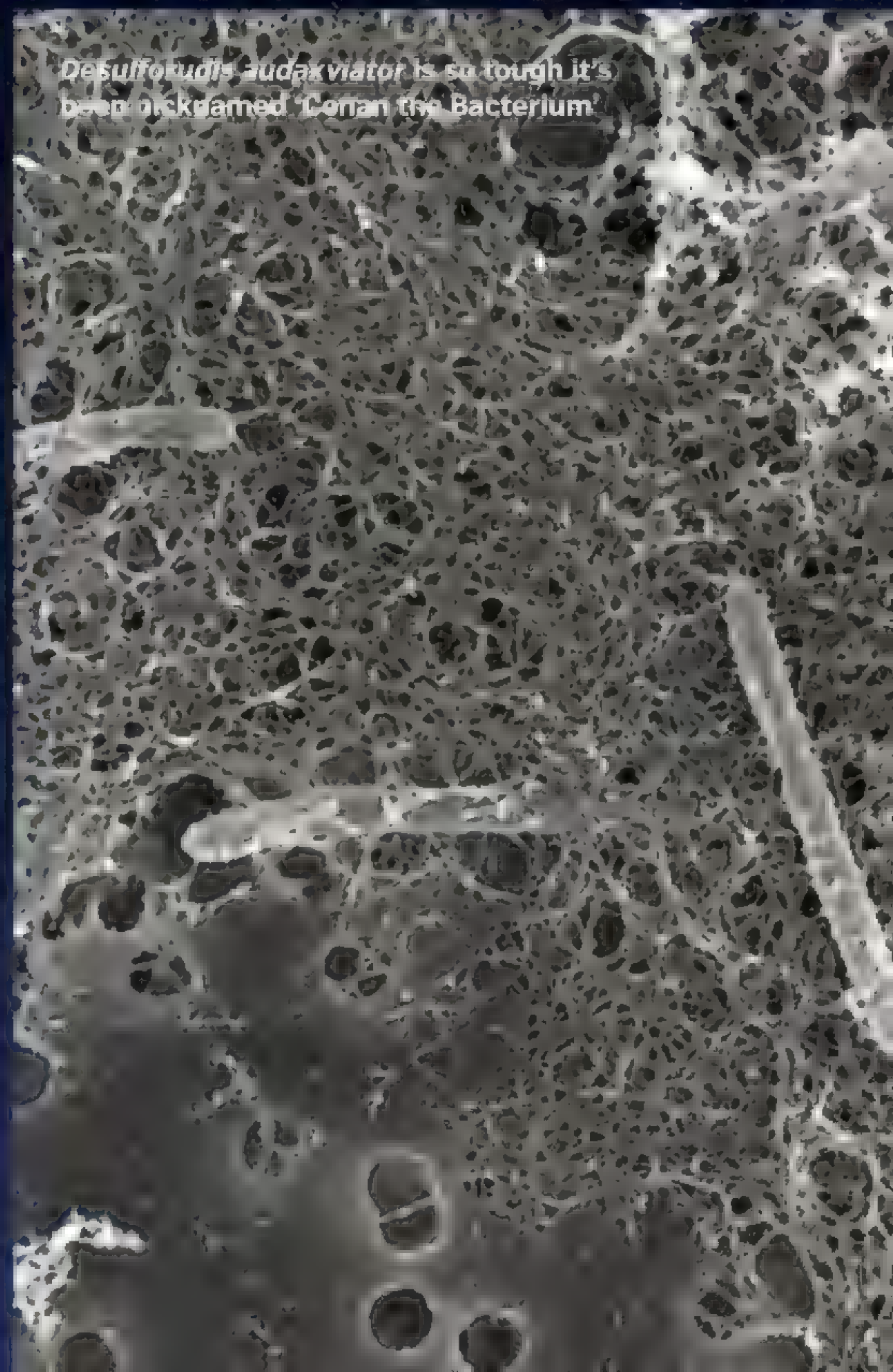
Bacteria and one hardy species of spider call Everest home



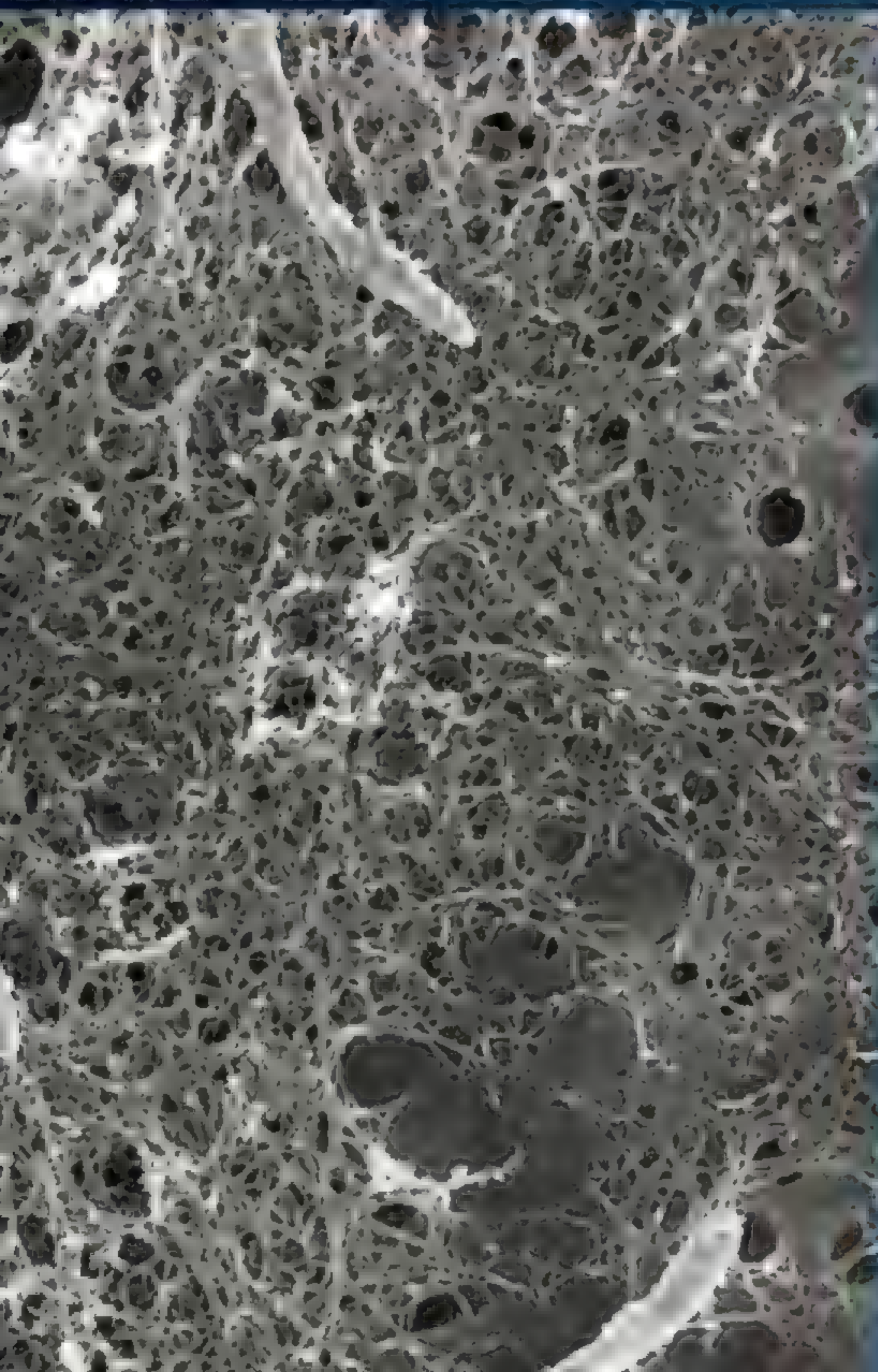
The bald notothen is a cod icefish native to the subzero waters around Antarctica



Scientists are studying extremophiles to better understand the origins of life and adaptations to extreme conditions



Desulfotudis audaxviator is so tough it's been nicknamed 'Conan the Bacterium'



in the rock. The groundwater is old and highly alkaline, and temperatures in the mine can reach 60 degrees Celsius.

D. audaxviator is the only known species that doesn't share its ecosystem with any other life form, and it's among just a few organisms that survive in the complete absence of light and oxygen. The name 'audaxviator' is a nod to its isolated subterranean life – it's part of an inscription found by the hero of Jules Verne's novel *Journey to the Center of the Earth* and means 'bold traveller'.

EXTREMOPHILES AND THE FUTURE

One of the reasons extremophiles are so exciting is that we still know relatively little about them. Every study into the hardy organisms reveals something new about their biology or the potential applications they could have in our lives. One extremophile found in stagnant water in an American cave system showed potential to destroy breast cancer cells. Another, *Deinococcus radiodurans*, is listed in the *Guinness Book of World Records* as the world's toughest bacterium; it's radiation- and acid-resistant and can survive vacuums and extreme cold. Its resistance to radiation is due to a set of antioxidants that protect its proteins, and

"The world's toughest bacterium may help us develop a treatment for radiation exposure"

researchers hope this knowledge will lead to the development of a recovery pill for people who have been exposed to radiation. On top of this, it produces proteins that emit infrared light. Scientists believe these fluorescent proteins could be used to light up cells and organisms and allow them to watch the processes taking place inside them for longer than is possible with the jellyfish proteins currently used by medical researchers and biologists.

Extremophiles were around when the planet was still forming and cooling, and they might hold some of the secrets to protecting it. Since they thrive in the most hostile parts of the planet, they have evolved to use whatever is around them. Organisms like those that rely on iron to digest food have the potential to remove harmful metals and industrial waste products from the environment.

One microorganism discovered in Rotorua, New Zealand, in a geothermal field known as 'Hell's gate' prefers acidic conditions and survives solely on a diet of methane. This species could one day be used to reduce gas emissions from landfill sites and thereby help in the fight against global warming.

Given the rate at which they're now being discovered and the variety of abilities they possess, tiny extremophiles could soon be taking a big step into the spotlight.

Life in the smoker

Hydrothermal vents found deep in the ocean are a surprising location for organisms to thrive

Water of life

As cold seawater seeps through the cracks in the seabed it dissolves vital nutrients and minerals which support many organisms in the area.

Hotting up

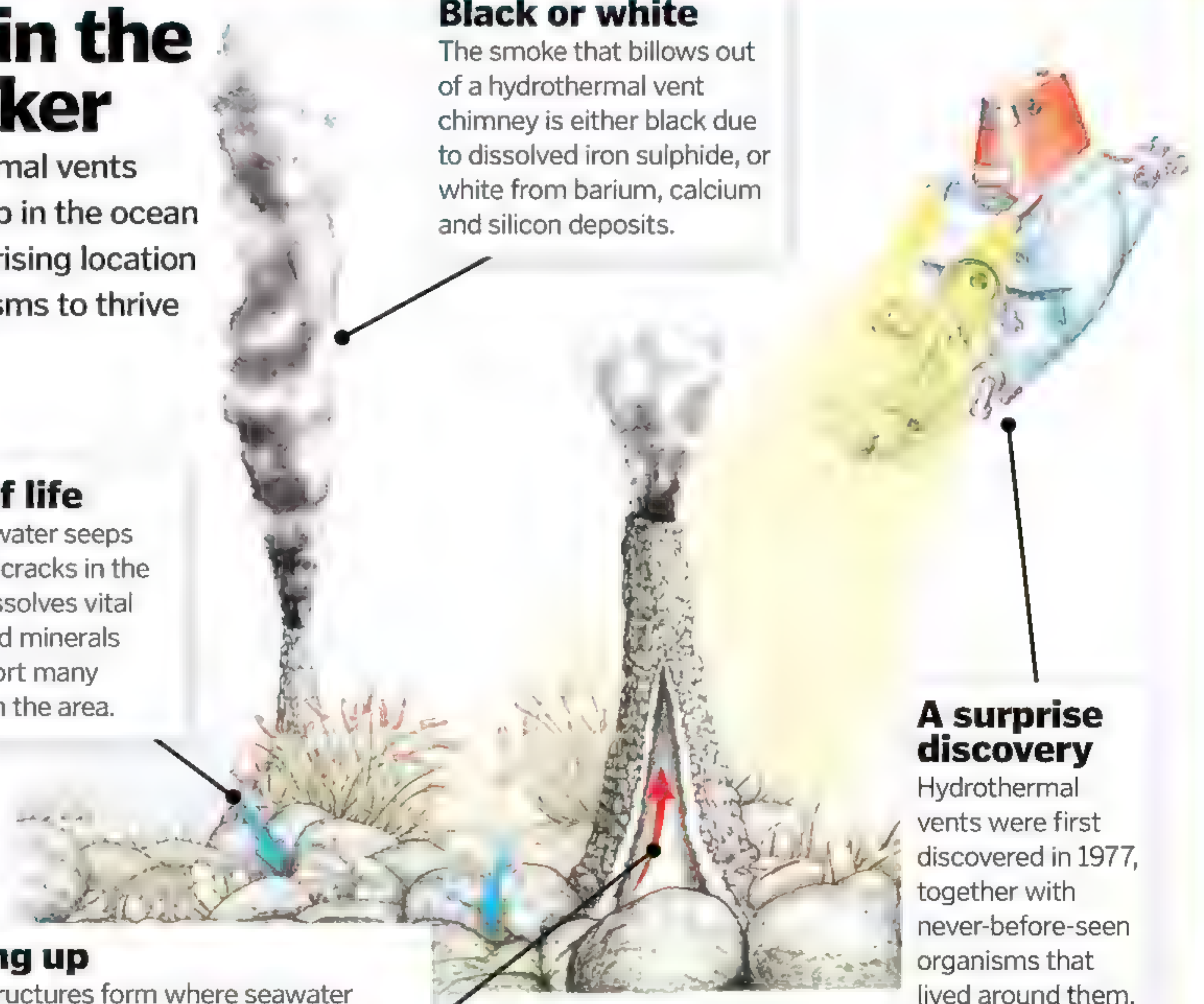
These structures form where seawater seeps through fissures in the Earth's crust and is then heated by magma below. The process can heat vent water to over 370°C!

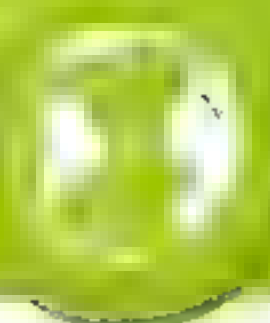
Black or white

The smoke that billows out of a hydrothermal vent chimney is either black due to dissolved iron sulphide, or white from barium, calcium and silicon deposits.

A surprise discovery

Hydrothermal vents were first discovered in 1977, together with never-before-seen organisms that lived around them.



**Spacious home**

The thrashing limbs of several enthusiastic frogs allow a mother to build a foam nest many times bigger than herself.

Complex building materials

Proteins within the female's secretion have antimicrobial properties and act as surfactants to stabilise the foam.

Air supply

The bubbly foam contains all the oxygen the developing tadpoles need while they're in the nest.

**Grey foam-nest tree frog**

Chiromantis xerampelina

Class Amphibia

Territory Central, Eastern and Southern Africa

Diet Insects

Lifespan Unknown

Adult weight Unknown

The foam-nest frog

Many legs make light work of these frothy egg holders

Chiromantis is a genus of frog found in Southeast Asia and the sub-Saharan tropics of Africa. These frogs are known as the foam-nest tree frogs because of the impressive frothy structures they create when rain signals the start of the breeding season.

While the foam nests may appear simple in comparison to other feats of animal architecture, they have some peculiar properties, and, in the case of the grey foam-nest

tree frog, are the work of many determined legs. Their nests are created when a female attracts multiple males, who will compete for access to her. The successful individual will then climb onto her back before she secretes a fluid that she will beat into a foam along with her mate, both frogs using their back legs to whip it up.

When a large nest of bubbles has formed the female begins to lay her eggs, which the male then fertilises. The process of frothing and egg

laying can take hours, so the female will have breaks to rehydrate. Other males will by now have arrived to contribute to the fertilisation process. When all her eggs are laid and fertilised the frogs part ways and the foam is left to develop a protective crust.

After four to six days the tadpoles are ready to hatch. The bottom of the nest becomes soft, so the tadpoles are able to wiggle out of their eggs and drop straight into the water below.



In-built meals

Developing within the nest, embryos rely on the nutrients in their eggs to help them survive and grow.

Big family

The foam nest needs to be roomy, because a female frog can lay thousands of eggs each breeding season.

Safe shelter

Under the hard outer layer the embryos are protected from microbes, predators and the harsh sunlight.

"The process can take hours, so the female will have breaks to rehydrate"

Other bubble builders



Fighting fish



Froghopper



Túngara frog

Waterfront property

The nest is carefully positioned over water so the tadpoles can drop safely when they hatch.



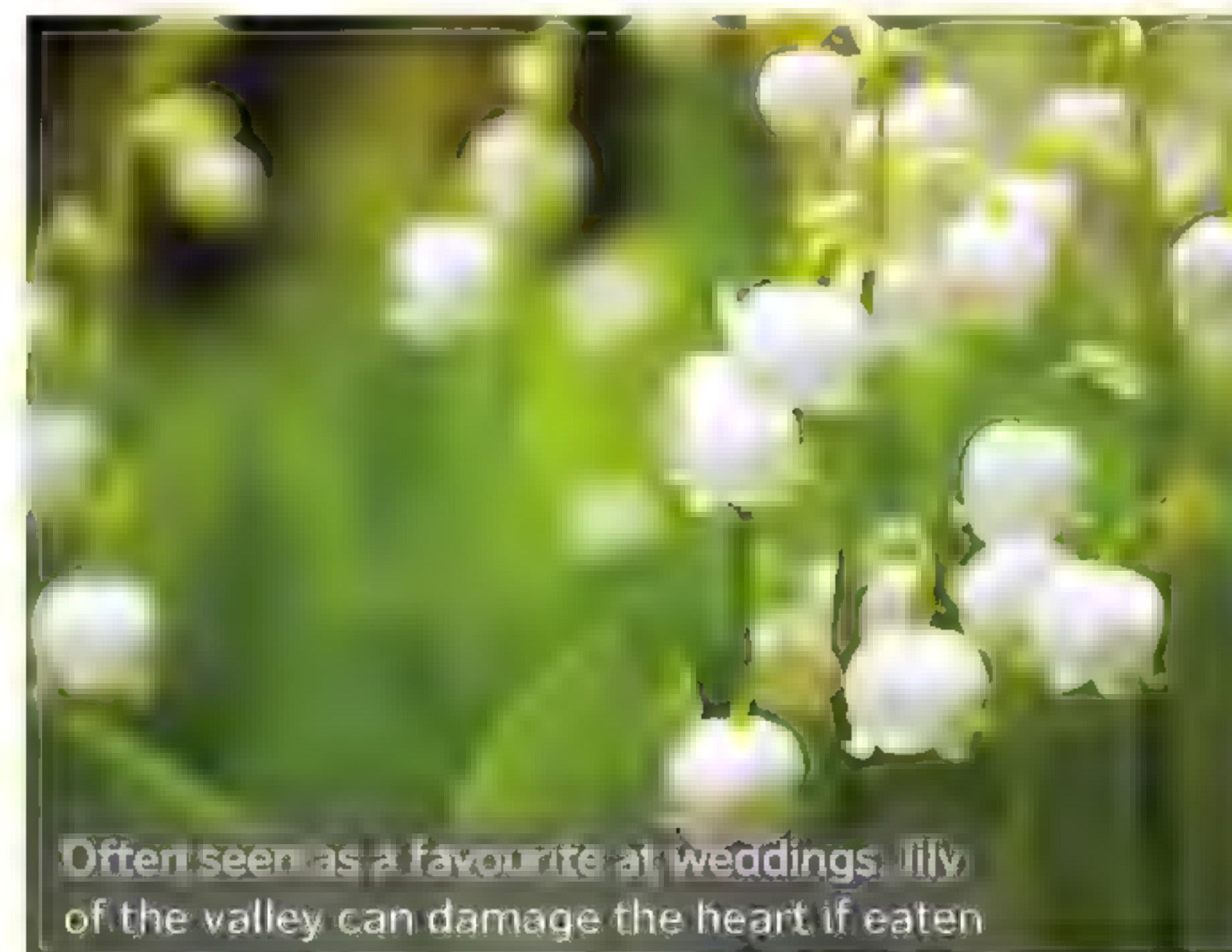
! DEADLY PLANTS



Whether they're hiding in the depths of the Amazon or growing in our back gardens, deadly plants have spread their roots across the globe. Because they are physically restricted in their ability to defend themselves against becoming a herbivore's dinner, some have evolved to produce nasty chemical compounds for defence.

Most plants considered 'deadly' to humans and animals use poison to protect themselves. A plant is defined as poisonous by its ability to cause harm or a fatality when eaten or touched by a living organism. Over millennia, poisonous plant species have come up with creative ways to defend themselves, each with their own style. Causing anything from cardiac arrests to blistering skin ulcers, a run-in with the wrong plant can send you to the emergency room.

Deadly plant toxins can be generally classified as having either toxic alkaloids, glycosides, oxalates or proteins – each offers their own nasty consequences when touched or otherwise ingested. One of the most poisonous plants on the planet, oleander, contains a deadly cardiac glycoside that can stop the heart after you've



Often seen as a favourite at weddings, lily of the valley can damage the heart if eaten

© Getty

ingested only a single one of the flowering plant's leaves.

Since the toxic chemicals are not used in oleander's biological cycles of growth or respiration, they must be present in the plant for the sole purpose of offering protection. Poisonous plants did not evolve alone, however – driven by the ability to adapt to their environment and its edible bounty, some animal species co-evolved to withstand the deadly nature of some plants. The koala is a common example of a species' ability to negate the toxic powers of its meal, in this case eucalyptus

"Causing anything from cardiac arrests to blistering skin ulcers, a run-in with the wrong plant can send you to the emergency room"

Discover the world's most dangerous plants, their poisons and how they 'hunt'

Words by **Scott Dutfield**

Stealing poison power

Over half of the world's poisonous plants live in tropical rainforests, where some have evolved to make the ground so that they can get to the roots. Scientists at the Botanical Institute in Oxford, England, discovered that some plants use their roots to pump out toxic chemicals that can kill insects.

The team found that a collection of leaves from a tree in the rainforest had a chemical called pyrrolizidine alkaloid (PA) which is poisonous to many insects. This is due to an enzyme within the leaves that converts the PA into a toxic form. The team found that the PA is then ingested by the insects and the PA is then ingested into the insects' bodies. The team found that the PA is then ingested into the insects' bodies. The team found that the PA is then ingested into the insects' bodies.

Other researchers, such as the Colorado State University team, have found that some plants use their roots to pump out toxic chemicals that can kill insects. The team found that the PA is then ingested into the insects' bodies. The team found that the PA is then ingested into the insects' bodies.





Deadly grip

How does the Venus flytrap capture its victims and turn them into fly stew?

Hairs

Known as trichomes, these sensory hairs detect the presence of potential prey.

Digestion

Scattered across the flytrap's folding leaf are digestive glands, which secrete digestive enzymes to break down their prey over 12 hours.

Trigger

The leafy trap begins to close and imprison its prey only after one hair has been touched twice.

Attraction

Deprived of any pollen or appealing petals to lure insects into their trap, these plants secrete a sweet nectar for flies to feast on.

Does a dock leaf heal a nettle sting?

Although it's not the most cloudy of plant species, a sting from the common nettle can still pick a nasty patch. Obedient on each leaf's surface are tiny hollow hairs laced with a cocktail of irritant, formic acid and histamines, which enter the skin when scratched.

To soothe the burning sensation of a nettle sting, rubbing the nearest dock leaf over the wound is often believed to help. Its cooling juices are often attributed to an alkaline sap that neutralises the acidic sting. However, this is simply not the case. It's possible that the moderation of the dock leaves' moisture on the skin may cool the burning sensation, but its famous healing abilities are a myth.



"There is a killer collection of plants that feast on the flesh of passing insects and even amphibians"

leaves. Although they're toxic to most other species, eucalyptus leaves are detoxified by cytochrome P450 enzymes in the koala's large caecum (digestive pouch). These enzymes break down the toxins rapidly, allowing the animals to consume the leaves without fear of injury. However, due to the low-calorie value of the eucalyptus, koalas have to consume about 400 grams of leaves and sleep for up to 22 hours.

Packing poisons is only one of the many ways plants are some of the most deadly organisms on Earth. Although harmless to human hands, there is a killer collection of plants that feast on the flesh of passing insects and even amphibians. Known as carnivorous plants, Venus flytraps and pitcher plants have evolved to not only take sustenance from traditional methods of photosynthesis but also actively eat passing prey. Typically, these pitcher plants feast on a variety of insects, but a recent study found that one in five pitcher plants in Ontario, Canada's Algonquin Provincial Park have been chowing down on juvenile salamanders. The way these saxophone-shaped plants digest their

prey is by luring them into a pool of collected rainwater. Once the salamanders have taken a dip, they cannot climb the pool's waxy walls and find themselves trapped. The pitcher plant then secretes digestive enzymes into the salamander's watery grave.

Having died naturally from either starvation or overheating, the salamanders decompose in about ten days. The pitcher plant will then absorb its nutrients from this 'salamander stew' as a tasty treat.

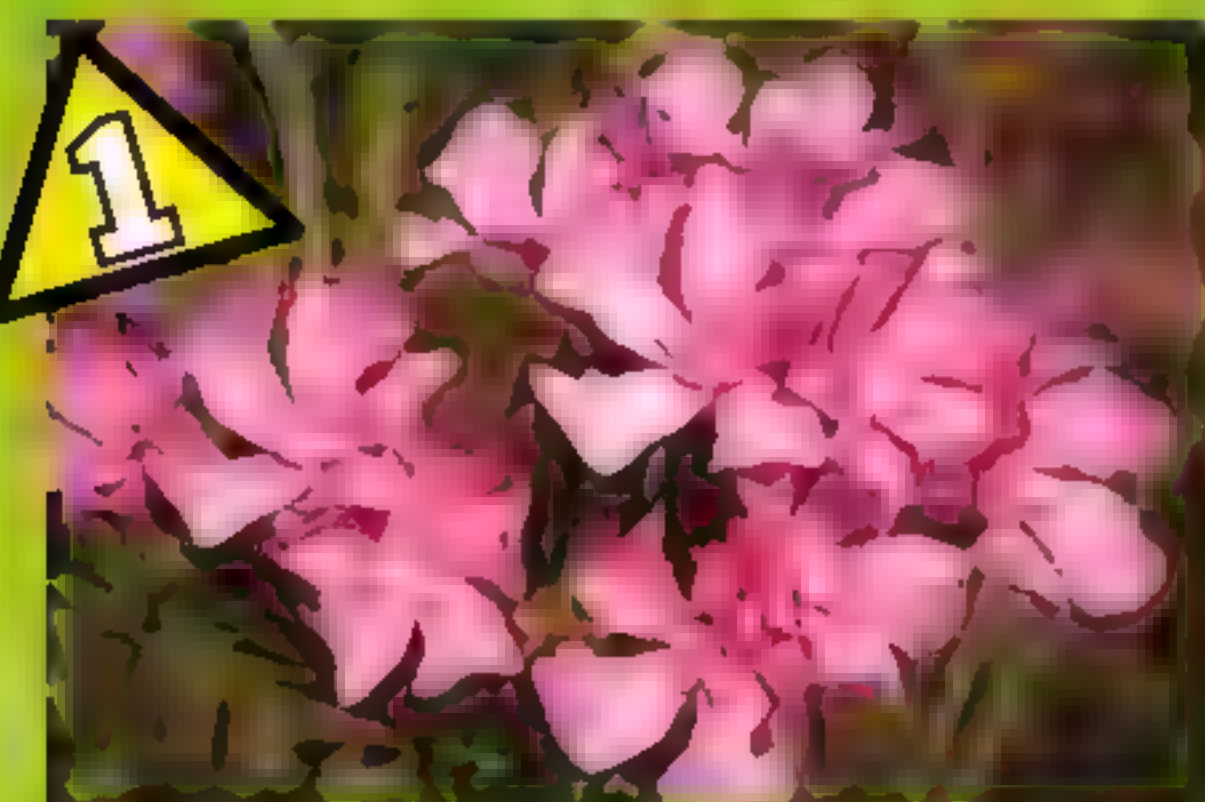


Having evolved an immunity to toxic leaves, koalas can feast on eucalyptus for hours.

Oleander
(*Nerium oleander*)

Native: Eurasia and North Africa

Generally considered the worst of the bunch, this plant is equipped with the toxin oleandrin, which causes vomiting, irregular heartbeats and even death. Ingesting one leaf is enough to be fatal.



Water hemlock
(*Cicuta maculata*)

Native: North America

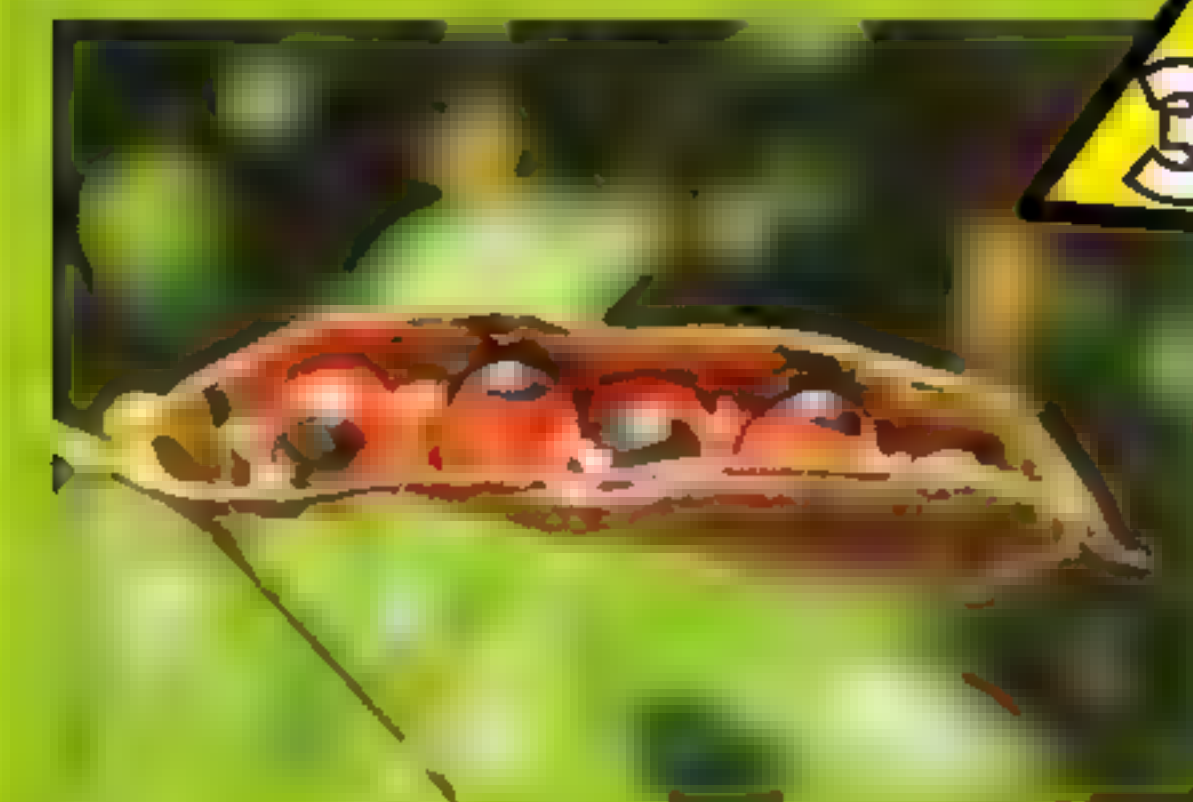
Don't be fooled by this plant's angelic flower: this is one of the world's most poisonous plants. Flowing through every part of the plant is a cicutoxin that can cause convulsions, muscle tremors and death. Toxins are highly concentrated in the roots.



Rosary pea
(*Abrus precatorius*)

Native: Asia and Australia

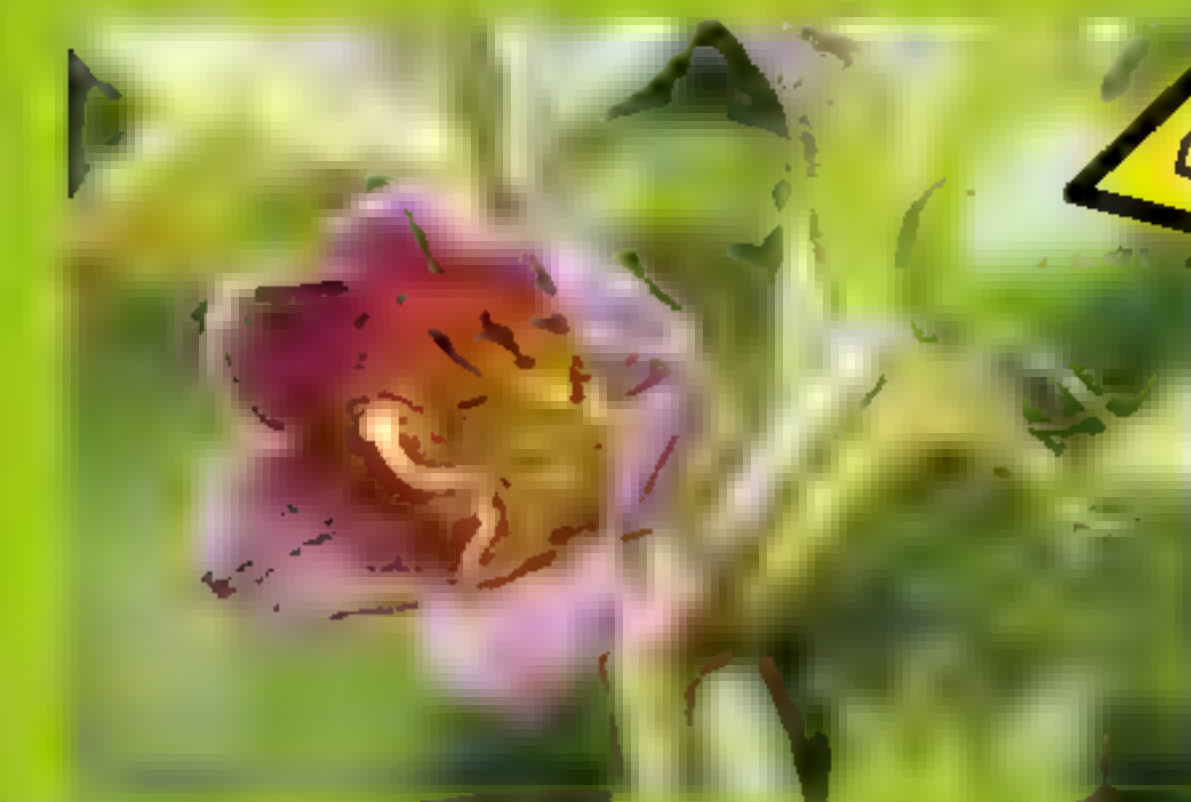
Less than three micrograms of the toxin abrin is enough to be fatal, making it deadlier than ricin. Oddly, the toxin is only held in the casing. Once that's broken, the abrin is released, but swallowing the seeds whole is relatively safe.



Deadly nightshade
(*Atropa belladonna*)

Native: Eurasia and North Africa

Deadly nightshade has a potent ability to paralyse the body's nerves. It causes injury to the heart and intestinal muscles, and it only takes ingesting ten to 20 berries to be fatal to an adult.



Castor bean
(*Ricinus communis*)

Native: East Africa

Although castor oil is safe and used in food and drug production as well as beauty products, the seeds contain the poison ricin. Eating an unprocessed bean can lead to internal bleeding, vomiting and circulation failure.



The 10 most poisonous plants



Suicide tree
(*Cerbera odollam*)

Native: Asia and Australia

The suicide tree is named for its seemingly harmless yet deadly fruit. Each seed is highly concentrated in a potent cardiac glycoside called cerberin. The seeds of the tree can slow down the heart's rhythm, sometimes to a fatal extent.



White snakeroot
(*Ageratina altissima*)

Native: North America

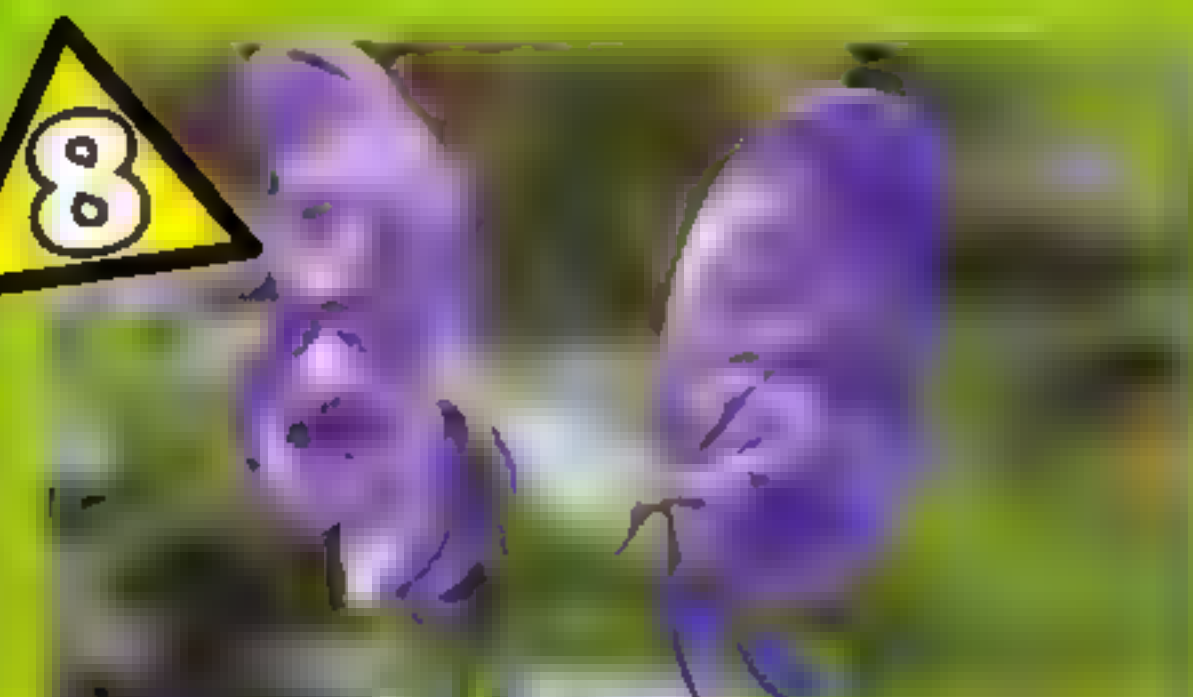
This plant can cause what is commonly known as milk sickness if ingested by cattle: meat and milk by-products can contain a toxic alcohol, known as trematol, that can lead to vomiting, muscle stiffness and death.



Aconite (*Aconitum napellus*)

Native: UK

Toxic to the touch, aconite can cause numbness and even heart difficulty after contact thanks to its alkaloid toxins. Often mistaken for horseradish roots, this plant can cause vomiting, high blood pressure and death when ingested.



Jimson weed
(*Datura stramonium*)

Native: Central America

Jimson weed, also called devil's snare, is a plant in the nightshade family. Ingested in high quantities, its poison can cause seizures or place you in a coma. Its alkaloid toxins have also been known to cause hallucinations.

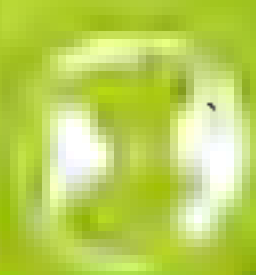


Manchineel tree
(*Hippomane mancinella*)

Native: Central America

Few poisonous plants can infect their victims by a simple touch. Laced with a cocktail of poisons, this tree's sap will cause irritation to the skin and eyes. Bite into the apple-like fruit and your mouth will quickly blister.





The Rainbow Mountain

Discover the origins of the colours cascading over Peru's iridescent Ausangate Mountain

Stretching over 7,200 kilometres along the western spine of South America, the Andes is the world's longest mountain range. It spans seven countries, but it is in Peru where one mountain in particular stands out from its surroundings.

Around 100 kilometres from the Peruvian city of Cusco is Vinicunca Mountain, which looks as though it's from the world of Dr Seuss rather than our own. Stripes of alternating yellows, reds and greens coat every undulation and edge of its rocky protrusions, giving the 'Rainbow Mountain' its nickname.

This multicoloured appearance is the result of millions of years of sediment layering. Over time, layers of different sediments with different mineral and chemical compositions (dependent on the environment at the time) covered one another. While exposed to Earth's

atmosphere, each layer's composition reacts with the elements in the air, such as oxygen. It's these interactions that produce the array of colours to form the mountain's rainbow appearance. Iron-rich sediment creates the red iron oxide layers, iron sulphide is responsible for the yellow layers and chlorites produce the green.

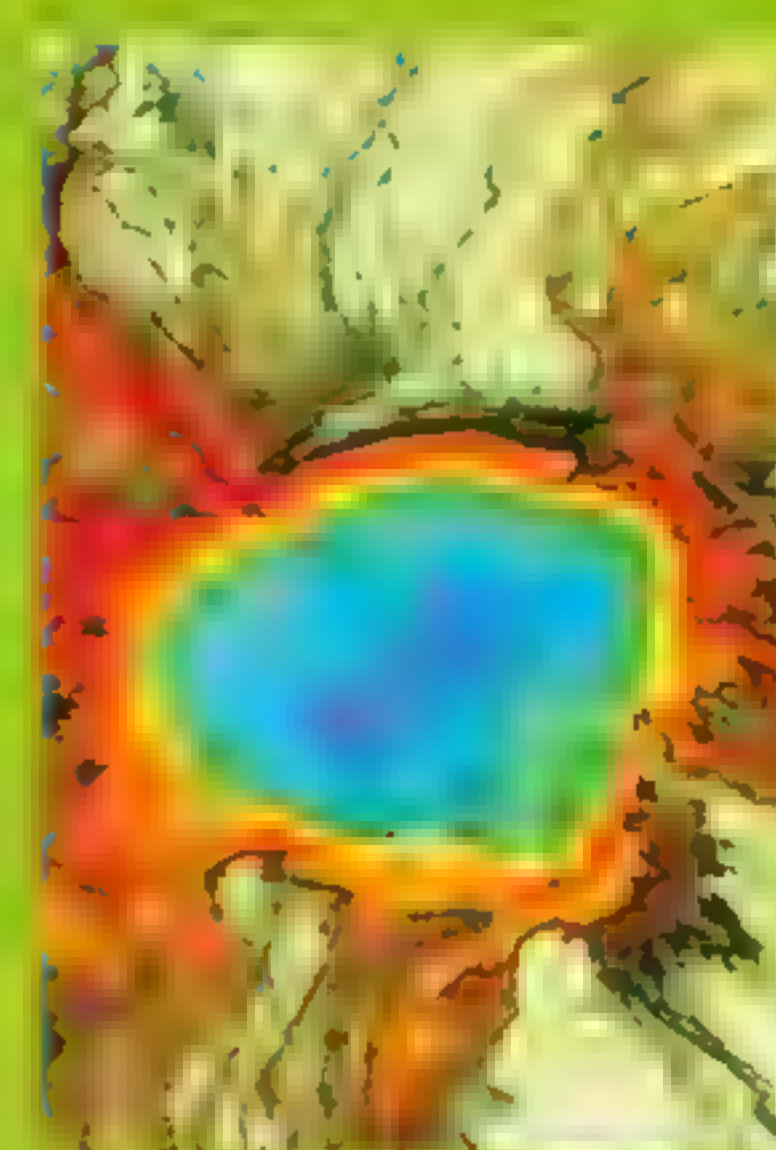
The Andes formed around 6 to 10 million years ago when the oceanic Nazca Plate subducted (slid underneath) the continental South American Plate, causing uplift. It is thought that this tectonic interaction also generated a lot of volcanic activity, which could explain the presence of the mountain's multicoloured minerals. Through millennia of further tectonic activity these sediment layers have been tilted on their side, so the stripes appear to run vertically.

Thousands of years of weathering has helped create the mountain's rusty shades

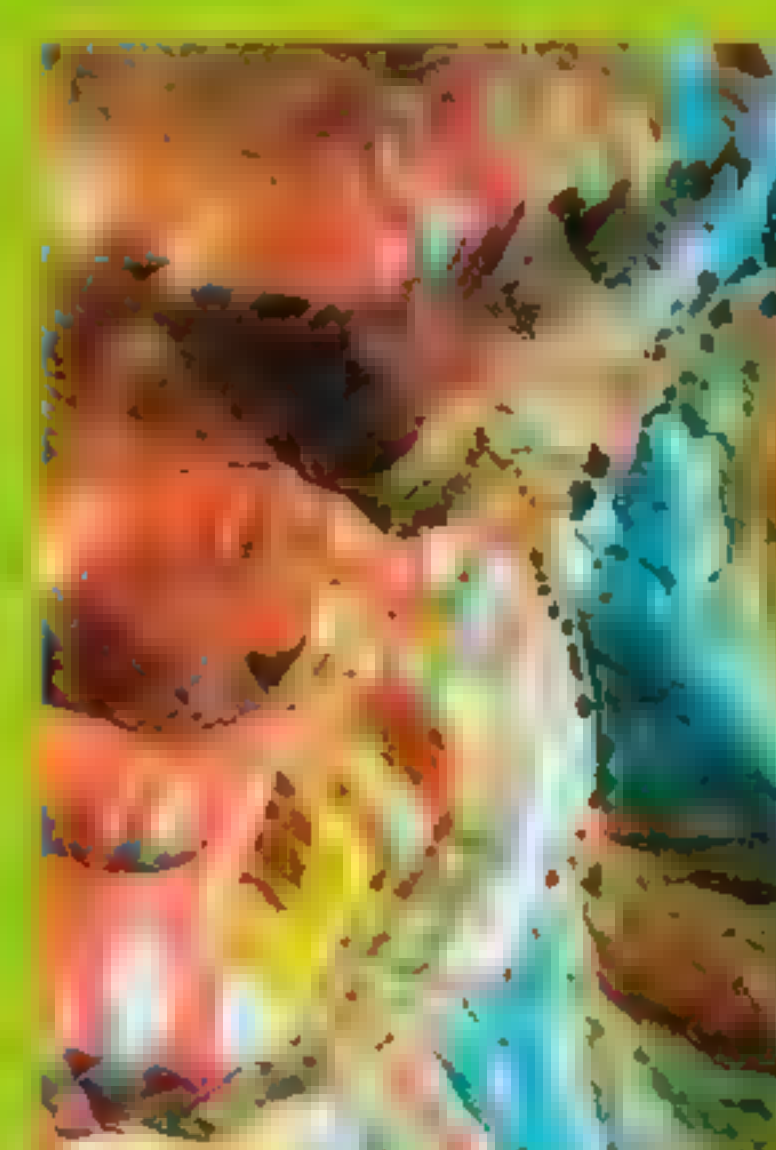
Earth's vibrant formations



Alum Bay, UK
These cliffs are composed of quartz, limestone and mica, but due to cementation from other minerals the cliffs display a variety of reds, oranges, yellows and browns.



The Grand Prismatic Spring, Wyoming, US
Formed in 1909, this spring hosts several species of bacteria, which contribute to its rainbow production.



Zhangye Danks, China
Known as the 'The Rainbow Mountains of China', these colorful sections of the mountains formed by a combination of their formation and impact.



Antelope Canyon, Arizona, US
One of the most photographed places on Earth, this canyon's flowing sandstone leads to a warm, orange, reddish and yellow, with a mix of red, orange, and yellow.



Big Geopet, Nevada, US
This semi-artificial formation was a failed attempt at a theme park. The rock is a mix of red, orange, and yellow, with a mix of red, orange, and yellow.

How coral reefs form

Corals are team players, collaborating to build the largest living structures on Earth

Covering just 0.1 per cent of the world's surface, coral reefs are home to around 25 per cent of all the species in the ocean.

These seemingly static structures are constantly surrounded by colour and movement, and while they're often mistaken for rocks or plants, the corals themselves are living animals; they belong to the group Cnidaria, along with jellyfish and sea anemones.

Corals can grow to vast sizes, but these aren't enormous individual animals – they're colonies made up of thousands of tiny creatures. On its own, each invertebrate is known as a coral polyp and can be as small as one centimetre in diameter. These polyps are sessile, meaning that they remain in a single spot once they've reached maturity and catch passing food with tentacles around their mouths.

The structure of a coral reef is provided mostly by the stony corals, or hard corals. These reef-building corals grow best in shallow tropical water with fast currents to bring food their way. Polyps slowly aggregate and connect their gastrovascular canals so they can share nutrients. Hard coral colonies gain their stony appearance through the secretion of calcium carbonate, a compound that forms a hard exoskeleton around the delicate polyps.

The hard skeletons and twisting shapes of reef corals provide shelter for a variety of creatures. Animals like shrimps and crabs defend homes made in the nooks between branches, and many species spawn around the reef to protect their young from the strong current. Single-celled algae called zooxanthellae even share the energy they produce from photosynthesis in exchange for lodgings within a polyp's body.

Life on the reef

From sea slugs to sharks, thousands of animals live on and around the coral reef

Coral reef snake

Sea snakes are highly venomous and spend most or even all of their lives underwater.

Nudibranch

Also known as sea slugs, these can be found in a range of remarkable colours and forms.

Fringing reef

Free-swimming coral larvae settle and attach themselves to submerged rocks.

Barrier reef

Fringing reefs around an island can join up to form a border around the whole coastline.

The making of a coral colony

Atoll

If a volcanic island subsides below the waves, it leaves behind a coral atoll.

Manta ray

With a wingspan that can exceed 4.5 metres, manta rays are majestic to behold as they swim in search of fish and plankton.

Reef shark

Several species of shark, such as the blacktip reef shark and the grey reef shark, hunt around coral reefs.

Lionfish

Most other animals stay away from lionfish – bright colours warn of the venom within their long spines.

Tube sponges

Growing slowly over hundreds of years, these can reach over 1.5 metres in height.

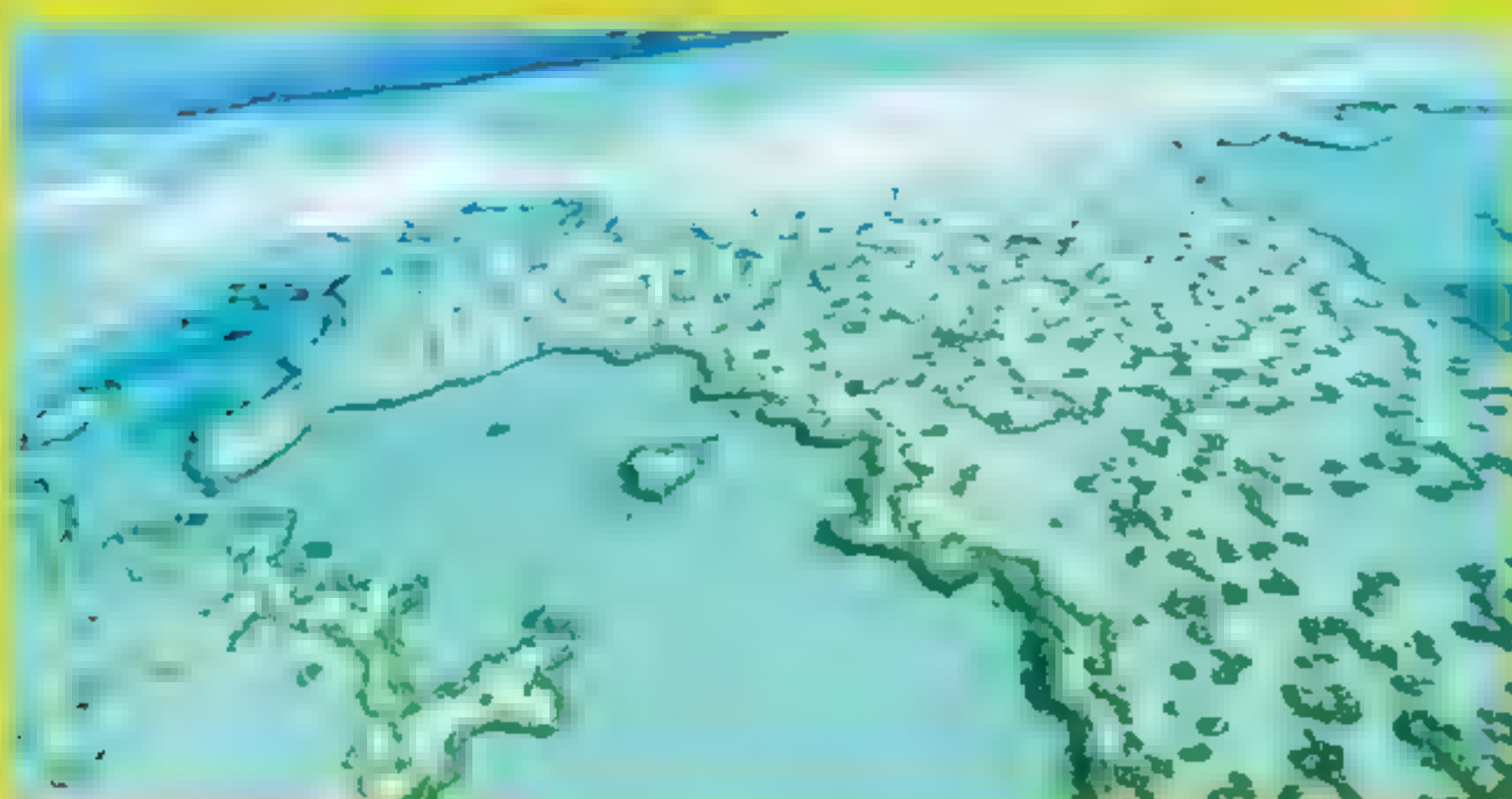


The Great Barrier Reef

Comprised of over 2,500 individual reef systems and hundreds of tropical islands, Australia's Great Barrier Reef is the most extensive reef ecosystem on the planet. It covers almost 350,000 square kilometres; it's so large, in fact, that it can be seen from space.

It has incredible biodiversity: 1,500 species of fish, 4,000 species of molluscs and some 240 species of birds call the reef home. Anemones and sponges add colour, while crustaceans and marine worms fill the reef with movement. Threatened species like the green turtle and dugong can still be found here, and clouds of butterflies head to the islands for the winter.

The Great Barrier Reef is a haven for wildlife. Most of the ecosystem's area has been a World Heritage Site since 1981, but its future is far from certain. Pollution, climate change, unsustainable fishing and coastal development all threaten this iconic reef.



1000 km (620 miles) long, the Great Barrier Reef is the world's largest natural structure made by living organisms.



ANIMAL ANTIDOTES

How do some creatures survive being bitten and stung by the most venomous nasties on Earth?

Words by **Scott Dutfield**

Whether it's the bite from a viper, a sting from a scorpion or the subtle swipe of a jellyfish, the world's venomous species have evolved the ability to deliver a killer cocktail of chemicals. However, there are those who have also evolved immunity to their effects.

There are roughly three types of venom among the more notorious of the 600 venomous species of snake. Neurotoxins affect the body's

nervous system, blocking communications between nerves and ultimately shutting it down altogether, resulting in paralysis. The second, hemotoxins, bring about a particularly gruesome demise. These toxins attack the body's red blood cells, making them coagulate to form gelatinous blood clots. Finally, cytotoxins are those that begin to digest the body's cells before the snake has even swallowed its prey.

As predators and as prey, venomous snakes are formidable opponents, but certain species are able to tackle them head-on without fear. The mongoose is the deadly cobra's worst nightmare. In order for this snake's neurotoxic venom to work the toxin must be able to bind with receptors on nerve cells. However, the mongoose's nerve receptors have mutated in a way that prevents this kind of binding, thus

Mongoose have evolved to resist the deadly venom of the cobra





...can jump a distance
up to four times
its body weight to
reach their prey

Kung-fu birds

Snakes can only jump to four times the length of attack from head but use the wings. Winged kung-fu killers, secretary birds have developed a muscular mid-section for fast lunging strikes. While not strictly all-terrain – they do not possess an overall versatility for tackling snakes – these birds avoid bites by using the speed of their feet to strike a snake's skull. One study found that an average of 100 per cent of secretary birds for the bird to strike the snake's head. Following a 20-km run down slope to the head, secretary birds are able to deliver a powerful strike with their feet, making the force of the blow.

Mongoose typically eat small animals such as snakes, birds and fish



Grasshopper mice have evolved the ability to simply brush off the sting of a scorpion



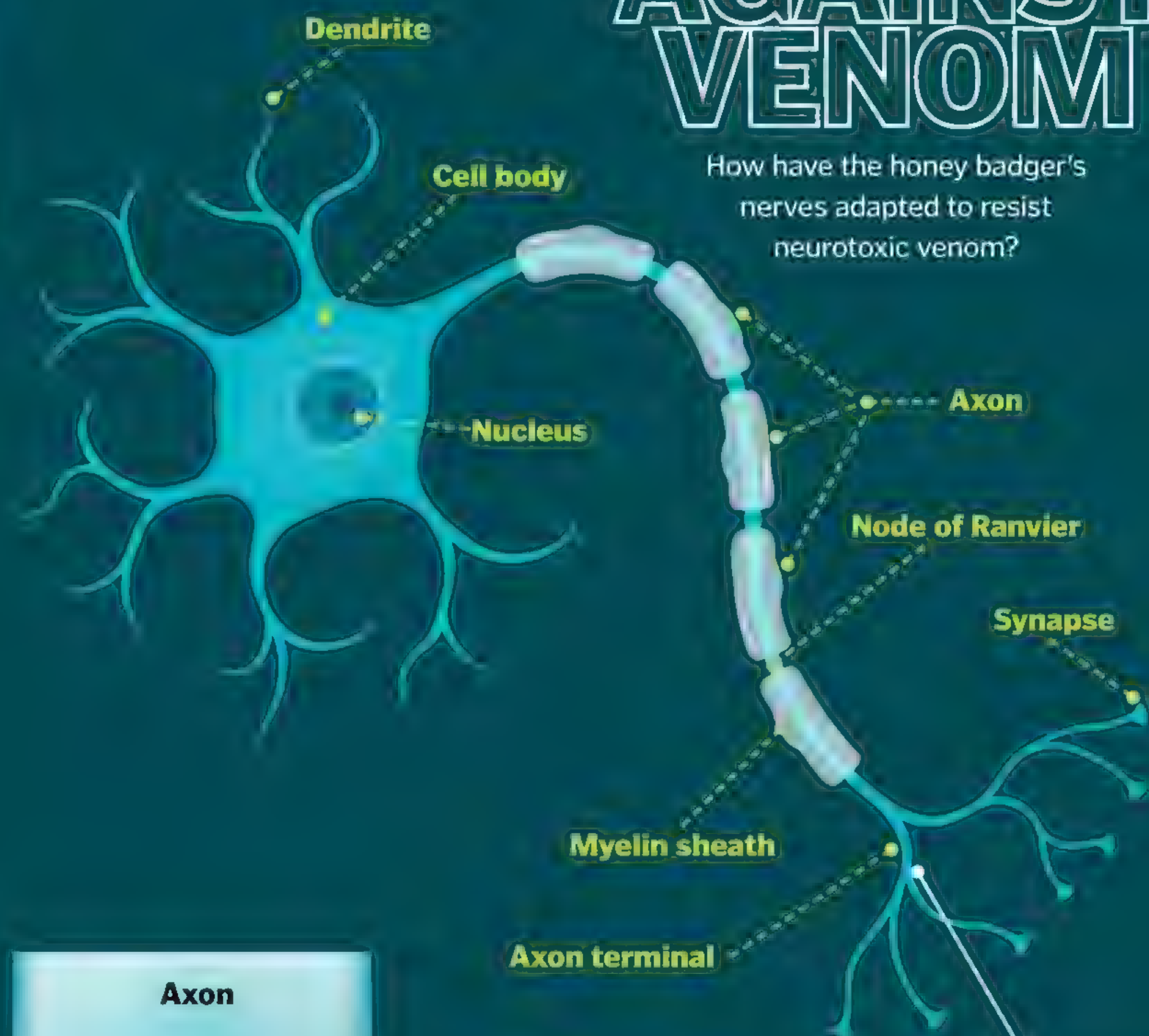
Rodent resistance

The sting of a scorpion can be fatal to many rodents who come in close contact with them. There is one, however, that has baffled researchers for not only its ability to prey on these sting-equipped insects, but to do so unscathed.

Native to the southwestern United States, the grasshopper mouse has taken a liking to the taste of bark scorpion. Deadly to other animals, when stung the desert-dwelling grasshopper mouse simply licks its paws and finishes its meal. It's still unclear exactly how the mouse is immune to the scorpion's sting, though it is thought to be related to a protein released at ion channels on the rodents' nerve cells. By binding with the injected toxin, these proteins are thought to actually create a numbing effect, reducing any pain felt by the mouse.

DEFENCE AGAINST VENOM

How have the honey badger's nerves adapted to resist neurotoxic venom?



Neurotransmitter

These are the nervous system's molecular messengers, carrying information between nerve cells.

Dendrite

Located at the head of nerve cells, these protrusions are where neurotransmitters are received from adjoining nerve cells.

Synaptic vesicle

Neurotransmitter

Axon terminal

Several of the protrusions at the end of a nerve cell deliver neurotransmitters to an adjacent nerve cell to pass a signal from the brain along the body.

Neurotoxin

Injected through the bite of a snake, these toxins travel to a synaptic cleft (where nerve communication is carried out) to bind with the nerve receptors and prevent the signal being carried forward.

Synaptic cleft

Dendrite

Mutation

In antivenom animals such as the honey badger these receptors have a mutated shape that still binds with neurotransmitters but is unable to bind with the neurotoxin.

Receptors

Channels are opened by neurotransmitters to allow sodium into a nerve cell to carry the electrical communication through the system.

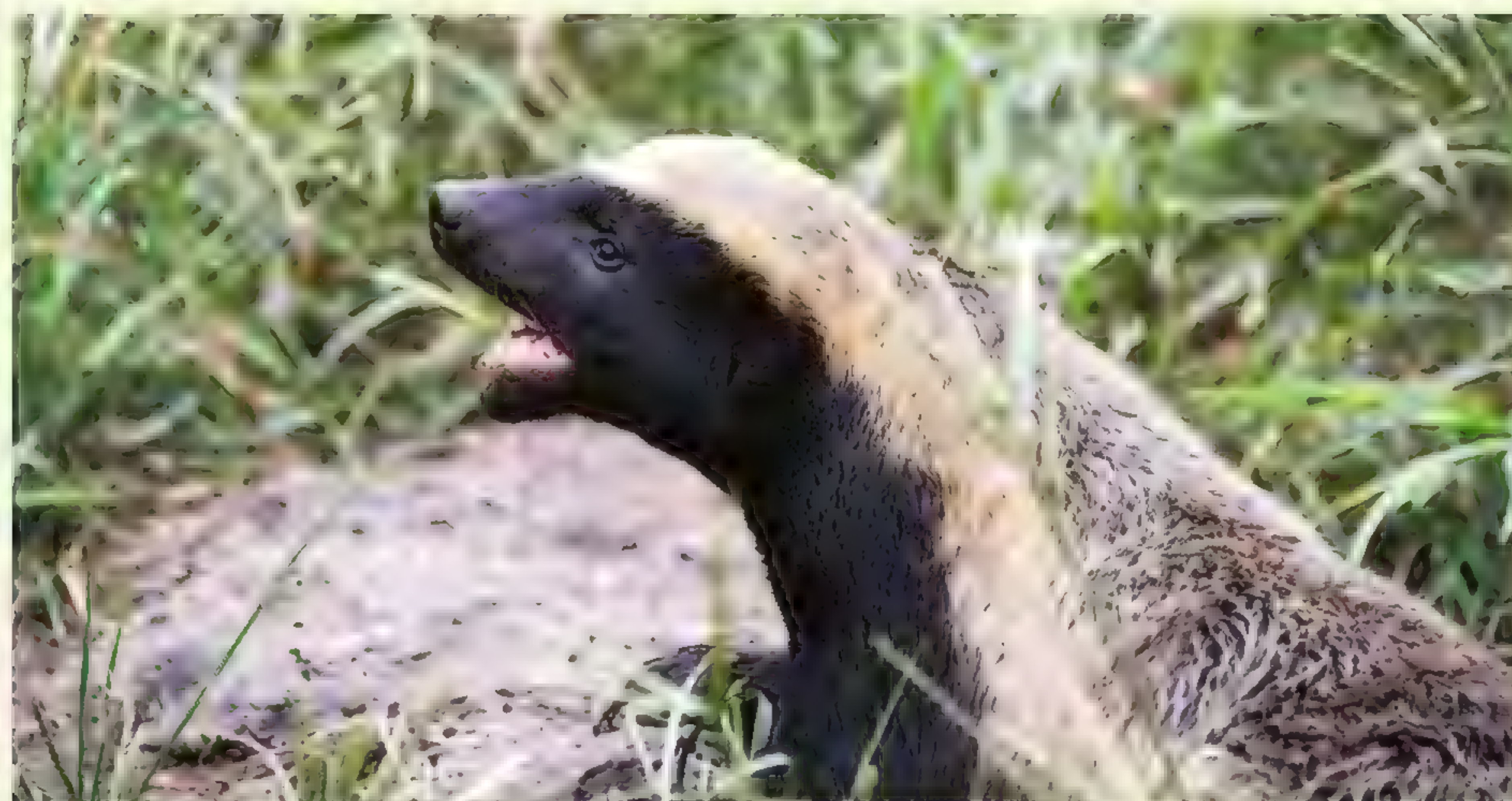
Na⁺

immunising it to their paralysing effects. The mongoose is not alone in its fight against the forces of neurotoxins: honey badgers, ground squirrels and even hedgehogs are among some of the mammals able to endure an otherwise fatal dose of neurotoxin from the fangs of a snake.

The North American opossum is also well-equipped for a battle in the bloodstream, with the ability to neutralise the venom of around 12 species of venomous snakes. The western diamondback rattlesnake, for example, is one such species. This snake's particular brand of toxin is a hemotoxic venom, which infiltrates the bloodstreams of their prey or aggressor, hijacks its blood cells and destroys their internal organs and circulatory system. The opossum, however, has a blood cell bodyguard in the form of a chain of amino acids in its blood that are able to neutralise invading venom.

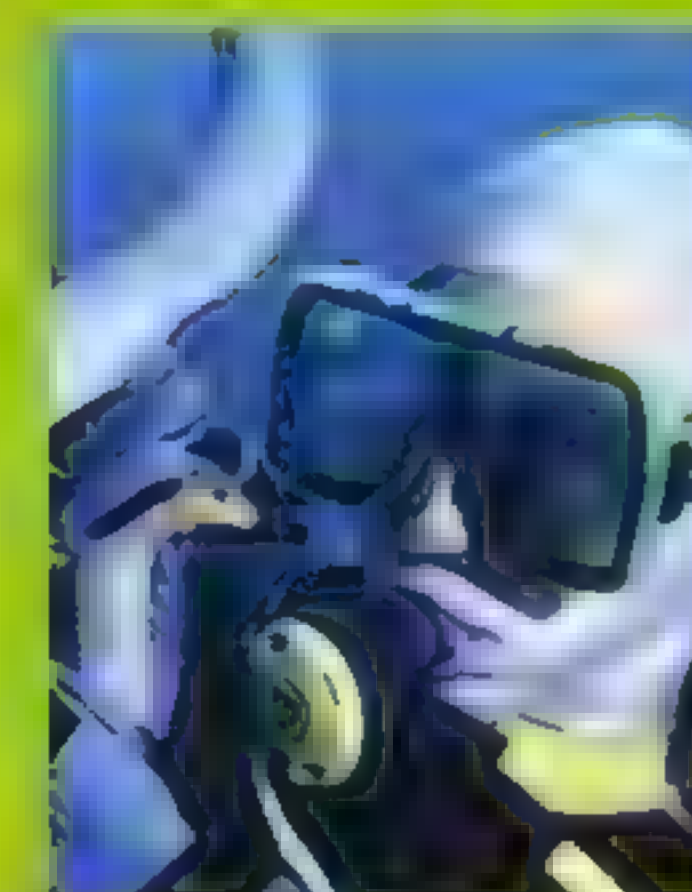
Arguably the world's most venomous species, the box jellyfish is able to disable and kill many living creatures in seconds. With each tentacle equipped with 5,000 stinging cells, these formidable creatures don't seem like potential food, yet leatherback turtles feast on jellyfish almost exclusively. Unlike the other mammal

antivenom members, leatherback turtles have a physical adaptation to defend against one of the world's most venomous jellyfish. Lining its thick oesophagus that leads towards its stomach are continuous rows of inward-facing papillae, or protrusions. Made from hard keratin, the same material found in fingernails, the sting of a jellyfish is rendered useless by them.



Q&A

Q&A with venom expert Bryan Fry



Have your responses reached critical mass? Do they seem to be?

That's the question you should be asking yourself at intervals of several hours, ranging from a couple of hours after you've completed responses to five or six hours after. That way you'll know if:

Examine various references from the same or different aspects and write your review.

Strong business understanding of internal
business environment and products
and the level of profitability of business/
product lines and business units
enabled strong performance in various
divisions. A rich history of successful
business transactions (past and present)
divisions and business units.



TREES of LIFE

OUR PLANET DEPENDS ON THE SURVIVAL OF TREES, BUT HOW DOES A SINGLE TREE SERVE ITS OWN ECOSYSTEM?

Words by Scott Dutfield



Reaching across millions of kilometres, the world's forests are the heart and soul of our global ecosystem. Trees are the yin to mankind's yang; they absorb the carbon dioxide we exhale, and in return they release the precious oxygen our bodies depend on, creating an atmospheric balance. During a tree's lifetime, it will absorb a ton of carbon dioxide, producing around 118 kilograms of oxygen a year in return.

While collectively acting as Earth's air purifier, each individual tree exists in its own micro-ecosystem. From seedling to skyscraper, trees are often at the centre of these ecosystems, supporting the demands for food, shelter and protection from other species. For example, a single tree growing in a tropical rainforest can support around 2,000 different species from across the animal kingdom as well as plant and fungi species.

Fundamentally the role of trees in a micro-ecosystem is to transfer energy in a biological chain, from sunlight to seed production and

beyond. Through photosynthesis, trees utilise the energy of the Sun's light to transform absorbed carbon dioxide and water into glucose and oxygen. Stored as chemical energy in glucose, a tree will use this to grow its leafy body and produce its fruits. This chemical energy is then transferred once more to the surrounding animals and insects via a free buffet of fruits,

"Each individual tree exists in its own micro-ecosystem"

leaves, pollen and nuts. In turn, these creatures will use this obtained energy to survive and even benefit the tree by dispersing its seeds.

This gifting of energy is not the only way in which trees serve members of a biological community. Non-living

'abiotic' parts of an ecosystem are also kept in check by the presence of trees. Both a tree and the soil it is rooted in mutually benefit from the other's existence. Soil acts as a tree's resource bank of water, minerals and nutrients to be withdrawn by its roots, while fallen leaves and branches restore nutrients to the ground as they decompose. The complex network of roots not only anchor the tree but compact the soil to save it from erosion by rainfall.

The biological and chemical interactions surrounding a single tree are intertwined and affected by the rest of the forest ecosystem and our global ecosystem. A disturbance to smaller ecosystems can have a domino effect on larger ones. For example, during the process of deforestation, each biological community supported by a single tree is also removed. In turn, this can have a negative effect on the diversity of species and the fertility of the land.



Gall wasp larvae release a chemical to create their own homes on a tree

The acorn and the wasp

Creating a habitat for animals and insects is a significant role of an oak tree, even when it's broken into pieces. In fact, across the leaves, bark and even among of many oak trees are small plant parasites called galls. Although they appear as part of the tree's natural ecology, development, galls are in fact the result of a particular group of wasps forcing the tree to build them their very own safe homes. Once laid in the tree, an adult gall wasp will leave its larvae to develop inside the galls, which will eventually break open, releasing the larvae. In response, the oak tree produces these strange growths, which protect the larvae within. Once released, the young larvae pupate and later emerge as adult wasps.



Gumivores such as the pygmy marmoset feast on the oozing sap of a tree

Continental forest coverage

Europe
10.15 million square kilometres

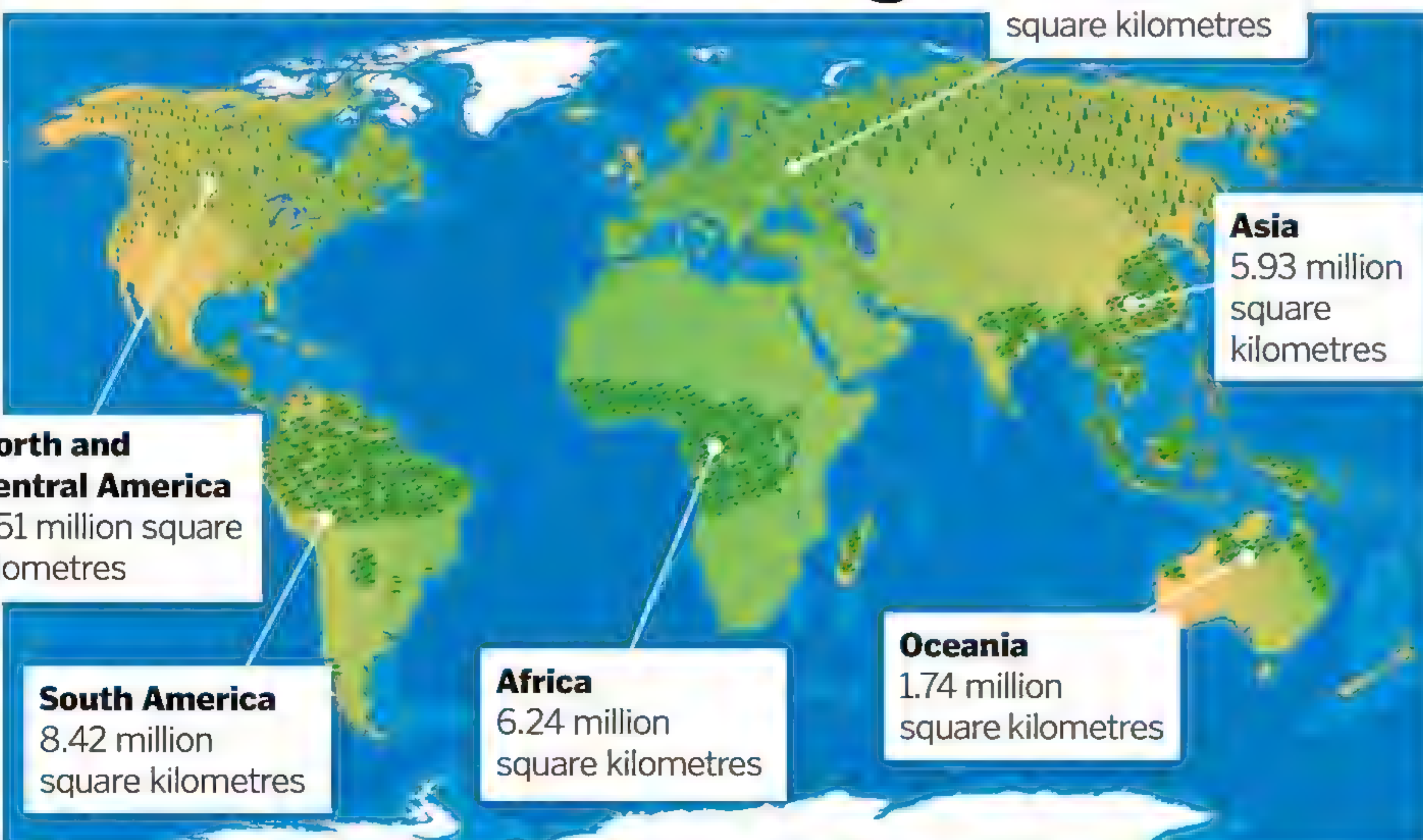
Asia
5.93 million square kilometres

North and Central America
7.51 million square kilometres

South America
8.42 million square kilometres

Africa
6.24 million square kilometres

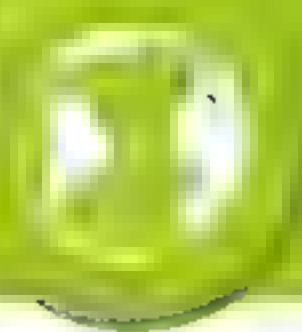
Oceania
1.74 million square kilometres



Many mammal species, such as the pine marten, make use of tree hollows to form their own home



Lichen can act as a biological indicator of the health of an ecosystem because it absorbs pollution



THE MIGHTY OAK

A single oak is brimming with biodiversity throughout the year

Seeds

Each acorn on an oak tree holds a single seed and will only be produced when a tree reaches the age of around 40 years old.

Rook



Autumn leaves

Once retired from their energy-producing role, dead leaves fall to fertilise the soil, forming what's known as humus.



Red kite



Green leaves

Photosynthesising leaves convert carbon dioxide and water into chemical energy and oxygen, sustaining the tree and the species around it.

Dispersal

Bird and insect species play a key role in dispersing seeds and pollen to facilitate the germination of the next generation of trees.

Eurasian collared dove



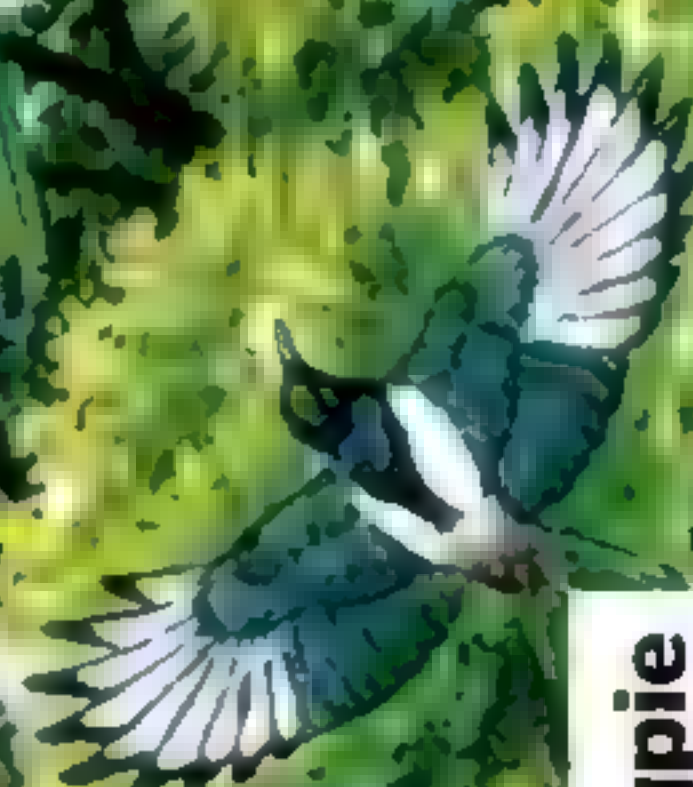
Golden oriole

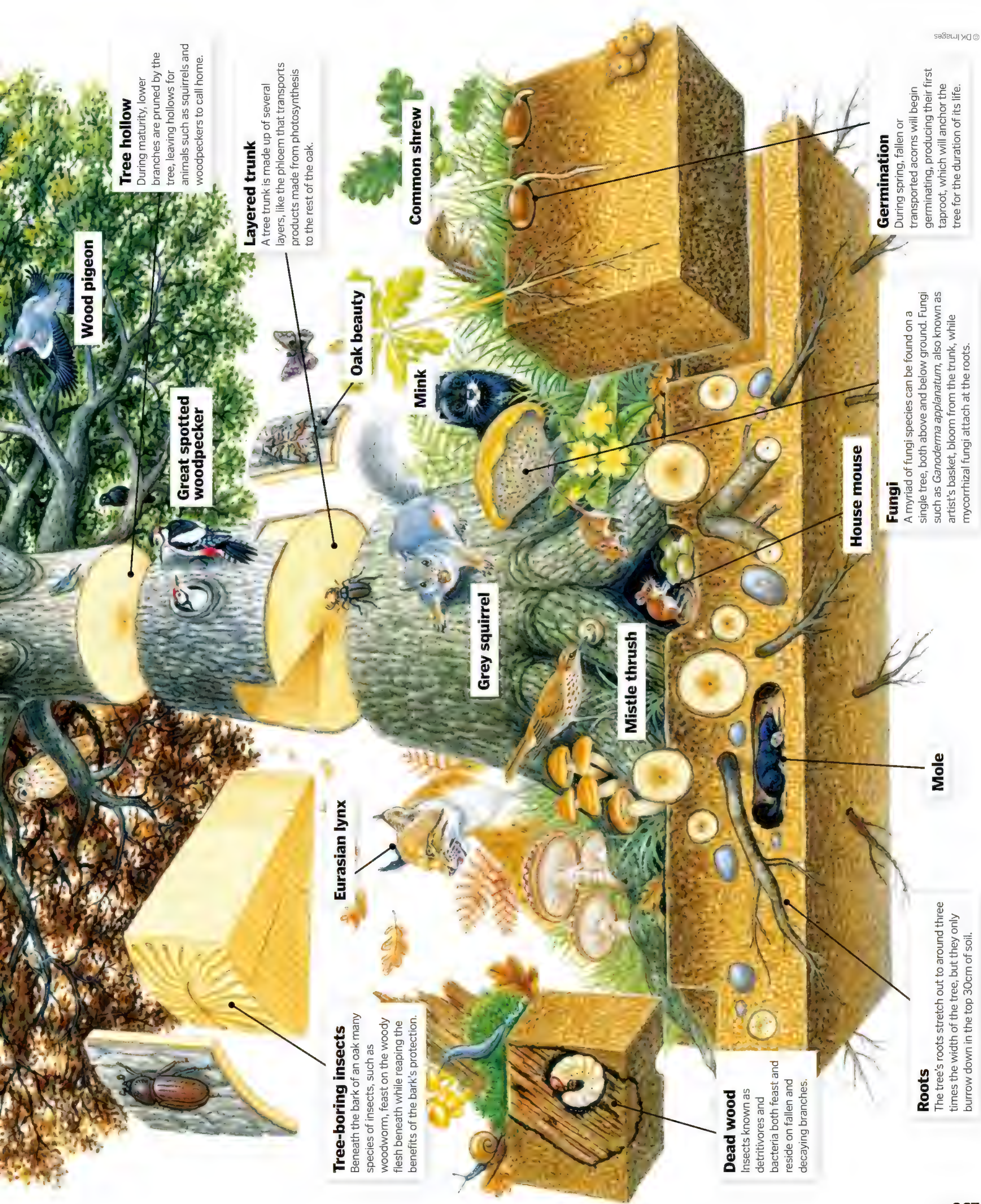


Blue tit



Magpie





Tree hollow

During maturity, lower branches are pruned by the tree, leaving hollows for animals such as squirrels and woodpeckers to call home.

Wood pigeon

Great spotted woodpecker

Layered trunk

A tree trunk is made up of several layers, like the phloem that transports products made from photosynthesis to the rest of the oak.

Oak beauty

Common shrew

Mink

Grey squirrel

Mistle thrush

House mouse

Germination

During spring, fallen or transported acorns will begin germinating, producing their first taproot, which will anchor the tree for the duration of its life.

Fungi

A myriad of fungi species can be found on a single tree, both above and below ground. Fungi such as *Ganoderma applanatum*, also known as artist's basket, bloom from the trunk, while mycorrhizal fungi attach at the roots.

Mole

Roots

The tree's roots stretch out to around three times the width of the tree, but they only burrow down in the top 30cm of soil.

Tree-boring insects

Beneath the bark of an oak many species of insects, such as woodworm, feast on the woody flesh beneath while reaping the benefits of the bark's protection.

Eurasian lynx

Dead wood

Insects known as detritivores and bacteria both feast and reside on fallen and decaying branches.



TECHNOLOGY

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Find out how special effects are made

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The birth of Dr Who's nemesis

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The pioneer behind mobile phones

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Tideway Tunnel



074
Designing
the Daleks

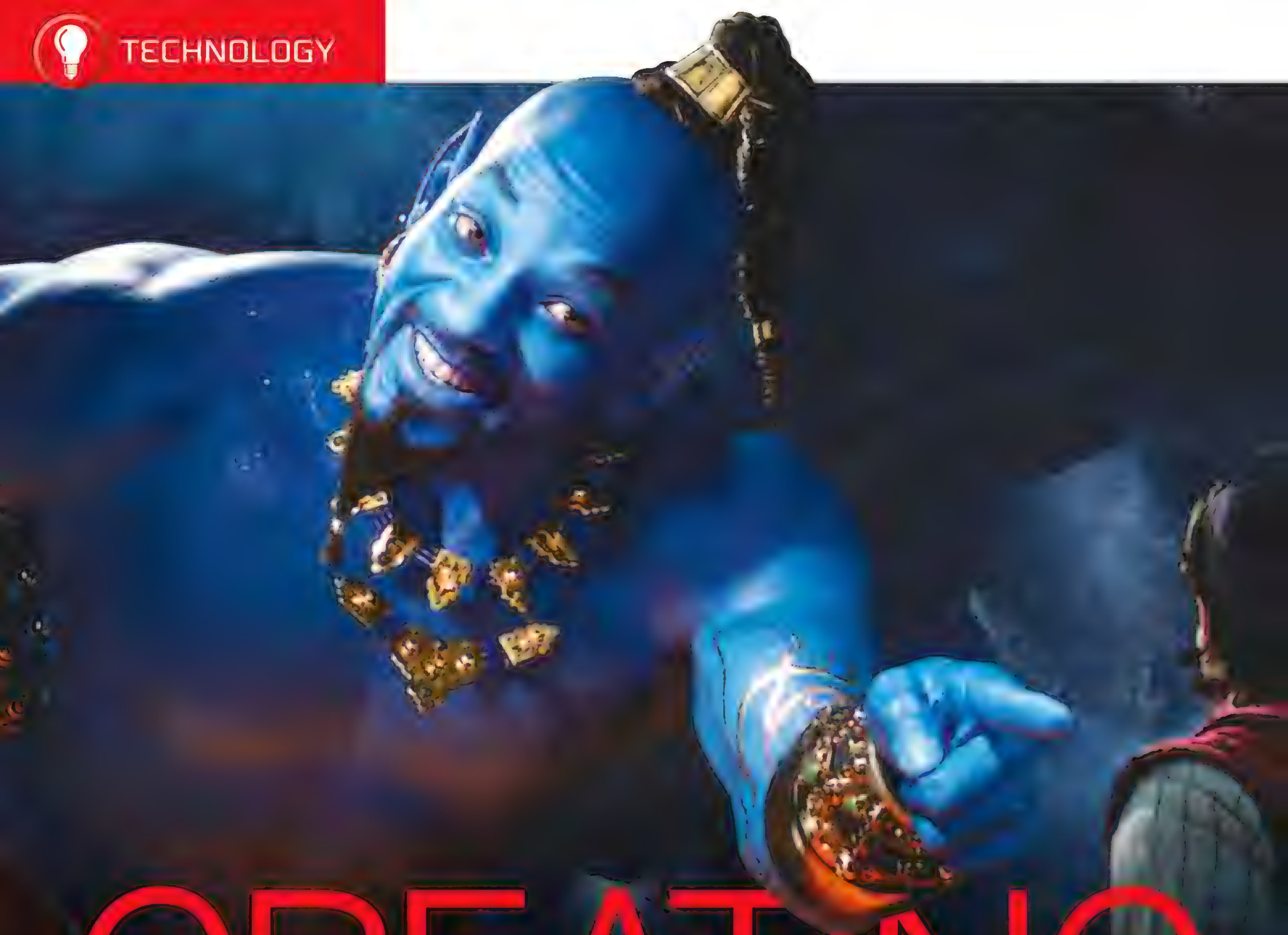


082
What's
inside a
waste
incinerator?



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The future
of medicine





CREATING MOVIE MAGIC

Discover how the cinema is brought to life with
computer-generated visual effects

Words by Scott Dutfield

Whether it's an explosion behind James Bond, the spellbinding sparks of Doctor Strange or Will Smith's genie makeover in *Aladdin*, visual effects play a vital role in conjuring movie magic. Ditching the days of rubber-faced monsters and visible strings, today's cinema

is bursting with the best that visual effects has to offer.

There are two ways in which movie magic can be cast upon a film – as either a special or visual effect. Special effects are typically those achieved on the physical movie set, such as explosions and animatronics,

whereas visual effects (VFX) are applied with computer programs after filming a scene, in the post-production stage. Using key techniques, VFX can range from simply changing the light to reflect the time of day to bringing to life a fantastical world drawn from an artist's imagination.

Helicopters can be transported to any location with the help of a green screen



Behind the green screen

The green screen is an iconic part of visual effects in movies and is also used in TV weather forecasts. Adding VFX via this method is known as 'keying', where artists replace sections of footage with different footage or computer-generated models, for example.

This is achieved by telling design software to remove a certain colour from footage, typically green or blue (depending on the screen colour) and replacing it with VFX elements. Actors in the scene can't wear that colour or their clothes and bodies would vanish into the background. Keying is used to digitally create surroundings that may be too dangerous or unobtainable in real life, or have simply been plucked from an artist's imagination.

'Feeling' colours

Numerous VFX artists and creators will work on a single feature film or TV show. One artistic arm of the production body is the colourists. Tasked with maintaining colour cohesion, saturation, vibrancy and tone, a colourist can manipulate the way an audience emotionally responds.

Colours are often associated with emotions. By identifying what emotion the film makers want, a colourist can highlight a colour or shade to promote that feeling. This emotion and colour relationship was outlined by psychologist Robert Plutchik, who created the Plutchik colour wheel of emotions. Colourists often use it as a reference.

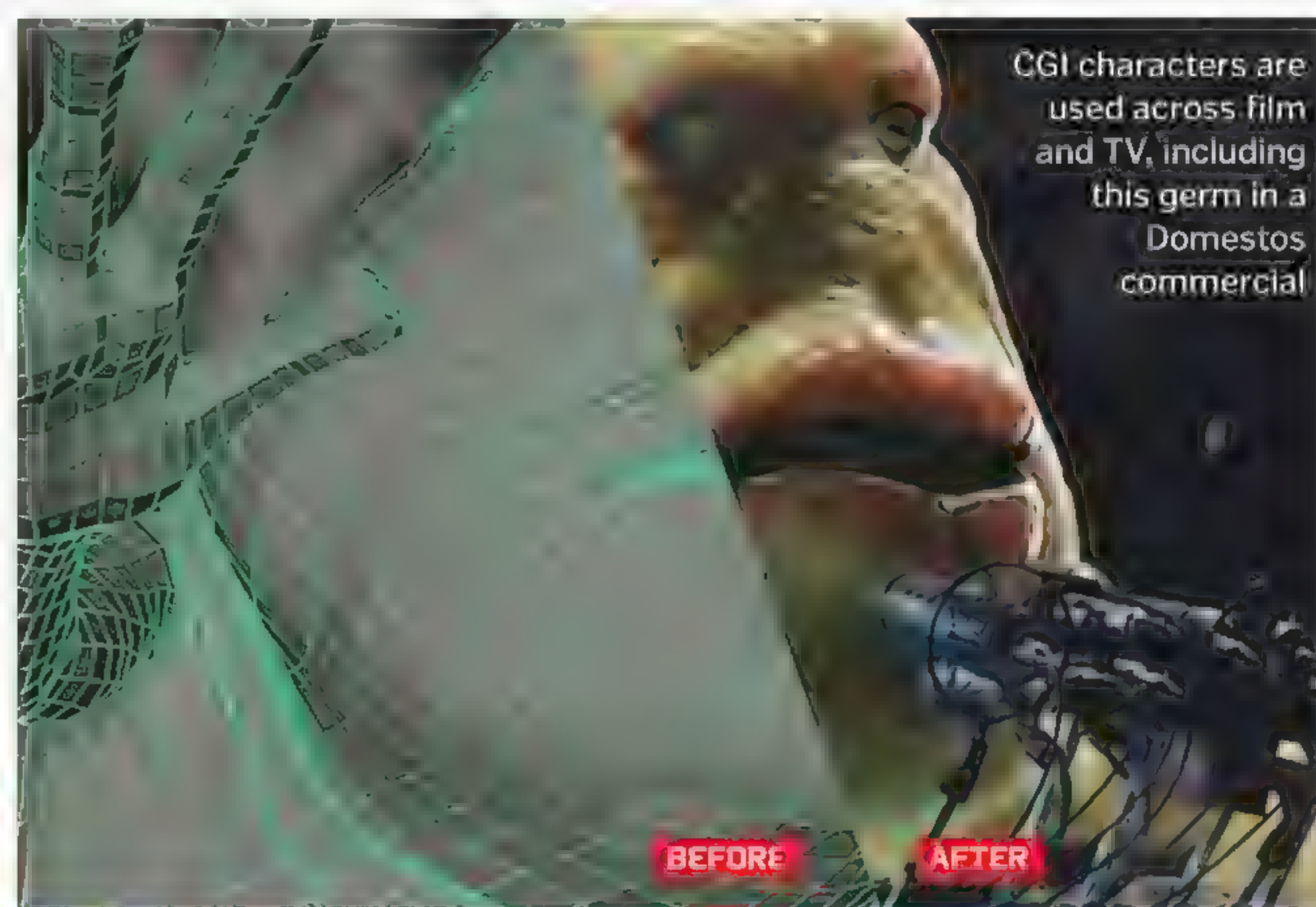


Creating a CGI cast

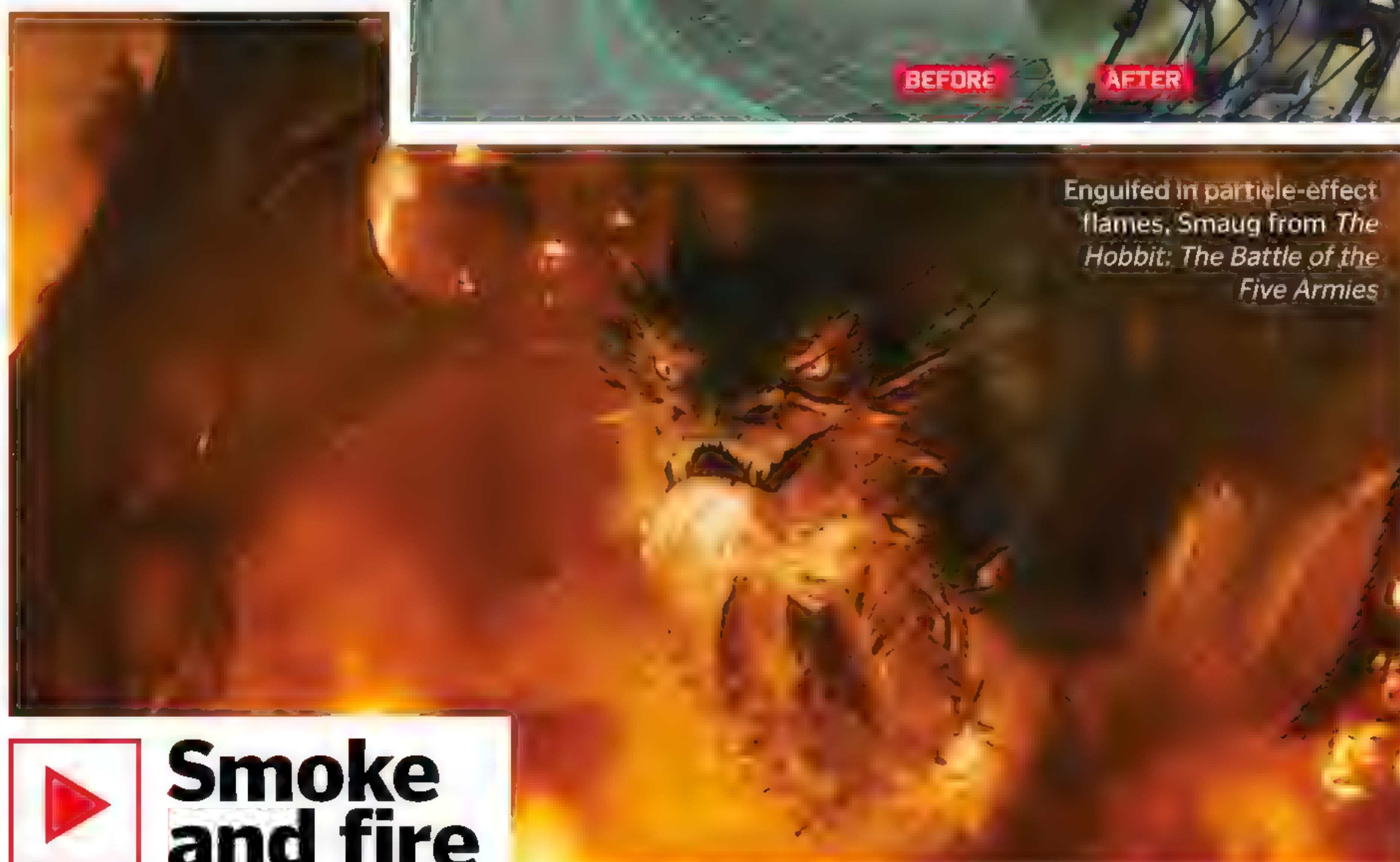
Computer-generated imagery (CGI) is a way to put any digital creation a designer can imagine into a scene. Creating a 3D CGI model can involve a digital version of clay sculpting. From concept art to digitally carving the final creation, CGI can achieve the impossible.

After compiling a series of computer-generated graphics, the final model is then textured, coloured and lighted, keeping in tone with the aesthetics of the movie. For a CGI model to then be animated, each limb, for example, is digitally linked together, almost like adding artificial tendons beneath the model's outer appearance. Known as rigging, this process then allows animators to take the designed model and puppeteer it in a scene.

Although animated, there are different considerations during the production of a CGI character in a live-action movie compared to a full-length animation film. Any CGI creation plays a role within a film, so human actors must interact with their environment on set as if the CGI character is there, while conversely the CGI characters must be puppeteered in a way to give the illusion it's reacting to the actors too.



CGI characters are used across film and TV, including this germ in a Domestos commercial



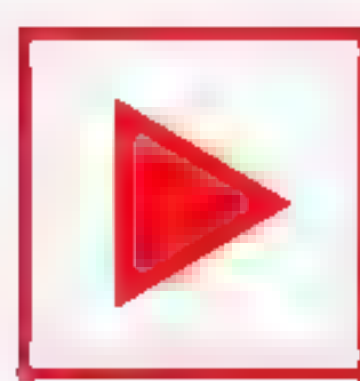
Engulfed in particle-effect flames, Smaug from *The Hobbit: The Battle of the Five Armies*

Smoke and fire

Smoke, fire or water can pose a problem for VFX artists. Impractical to digitally hand-draw or sculpt, artists use particle effects software like Houdini to realise their designs. Designers generate thousands of points, or particles, within the software, and by dictating each particle's movement, size, shape and colour, the

simulation of a fire, sandstorm or a waterfall can be created from scratch.

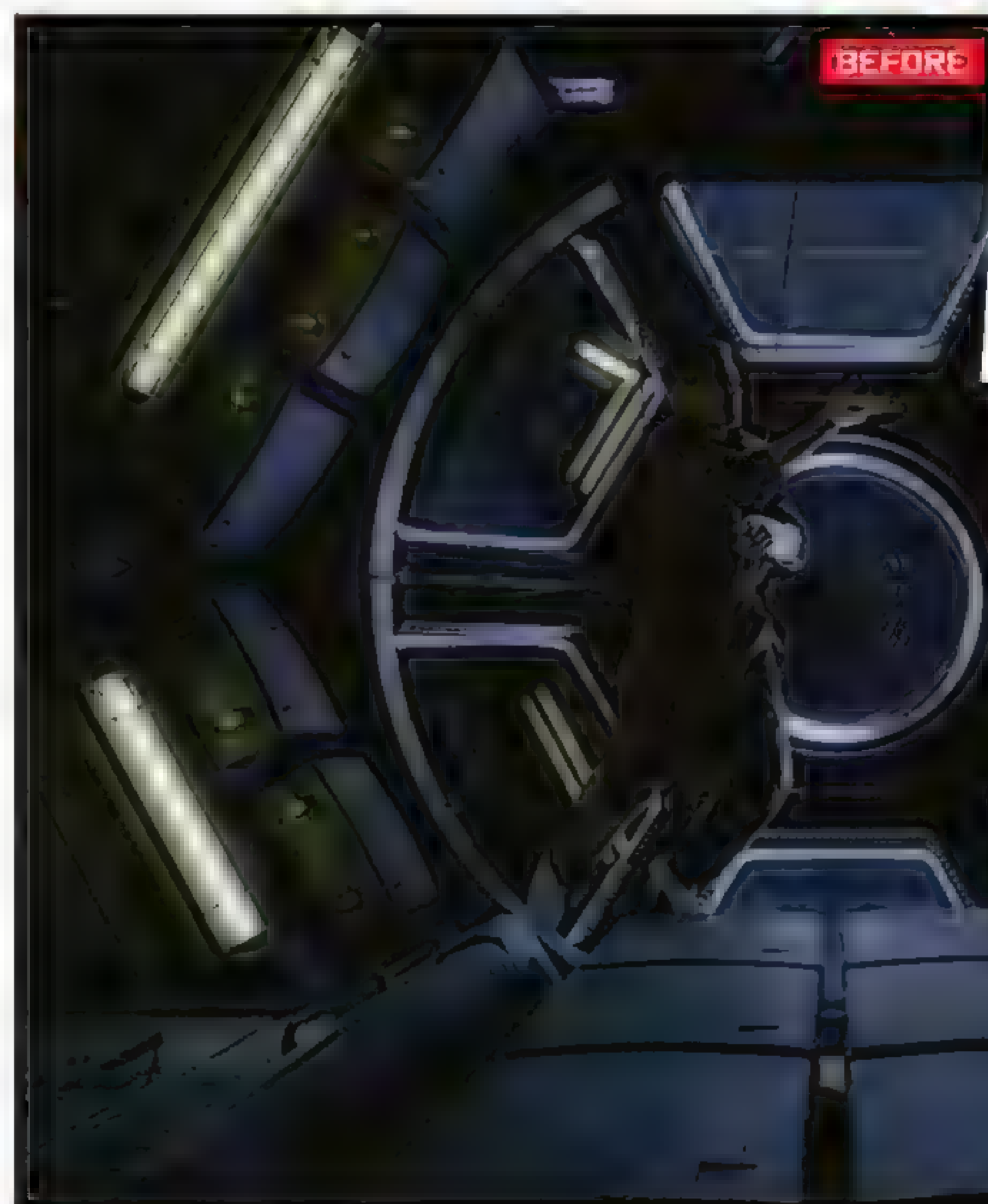
Much like the creation of a CGI character, particle effects require the artist to define the way each particle moves in order to mimic the natural movement of what they are trying to recreate, such as the fluid motion of water.



Cleaning up imperfections

It may seem as though current cinema has moved far beyond the use of strings to suspend flying objects, but in fact movie makers have just got better at scrubbing them off the screen.

Rotoscoping is a method used to isolate part of a frame and either remove or relocate it. By marking the outer parameters of an object, VFX artists are able to cut and paste footage frame by frame. For example, in any science fiction film scene in which a character is experiencing zero gravity (when in real life they are suspended on wires), scenes of their weightless motion can be cut out and pasted onto another background. This visual effect, however, is a time-consuming endeavour, as films are often shot at 24 frames a second.



The strings holding Jake Gyllenhaal in the antigravity thriller *Life* are easily removed with rotoscopy

© Outpost



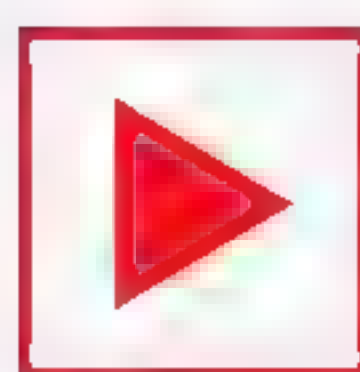
VFX elements surrounding a moving character are tracked and follow the motion of the camera

BEFORE

AFTER

"Combining the two exposed films resulted in a sequence that left audiences spellbound"

© Outpost



Seamless effects

Visual effects are only as effective as their ability to seamlessly integrate with a scene. Their value is directly tied to the audience's ability to believe that something computer-generated could really be interacting with live-action elements.

This is where tracking comes in handy. Tracking is the process in which all the VFX

elements in a shot follow the movement of an object, person or the direction of the camera in the original footage. If the movements of the added VFX elements are not in sync with the movement of the camera, the combination of the two feels disjointed, and the desired illusion is suddenly broken.

The magic of Méliès

The art of visual effects is not a concept new to the 21st century, nor the 20th. In the late 1800s magician and future film revolutionary Georges Méliès put the wheels in motion for visual effects. Long before the use of green screen keying, Méliès created a technique known as 'matte' to composite different footage.

In his 1898 silent film *The Four Troublesome Heads* (*Un Homme De Tête*) Méliès appears to take his head off his body and place it on a table, repeating the impossible feat three times. In this original trick of early film, Méliès used a pane of glass painted with a black matte finish to block out his head. Rewinding the film, he then placed matte black over everything other than his head. Combining the two exposed films resulted in a sequence that left audiences spellbound.



Georges Méliès used pioneering techniques to create spectacular illusions on film

© Outpost

DID YOU KNOW? In *Avengers: Infinity War* there are 2,680 VFX shots, 253 of which are in the opening act

Matte painting

Rather than sculpt individual CGI models of surrounding features, a digitised 2D image is composited into the background.

CGI

3D computer-generated elements, such as these train signals, are composed within each frame.

Lighting

Visual effects can be as simple as altering the time of day that a scene appears on screen by changing the shot's light and colouring.

Rotoscoping

Undesirable elements are masked or rotoscoped out of a shot, and another effect or image is added in its place.

Keying

Blue screen footstones are used to seamlessly integrate the train track visual effect and the actor's movements.

Tracking

All VFX elements are tracked and follow the movement and direction of the camera.



Piecing the puzzle together

This is the process whereby all of the VFX elements are brought together. Like a digital jigsaw, each effect and piece of film footage can layer over one another, a method known as compositing. This process can be as straightforward as dropping in a new background, while in heavy VFX scenes several elements need to be compiled and composited, creating several layers to form the final product.

Dissecting a scene

Frame by frame, how VFX experts fill a single scene with different visual effects



Body swapping

Motion capture brought to life characters such as the inhabitants of Pandora in *Avatar* and the beast from *Beauty and the Beast*. Combining real life and the digital world, 3D motion capture transforms actors into their computer-generated characters.

To make this transformation, actors wear a capture suit covered in small dots. These dots, known as tracking position markers, act as reference points to track the actor during a scene. In the VFX process, these points can be mapped onto the virtual skeleton of a computer-generated character, such as Gollum from *The Lord of the Rings*.

Digitally stitching both the real-life actor to their CGI character, the two appear as one on screen. Motion capture can also be used to add VFX to separate areas of the body, such as the hands or face, rather than the entire body.

In *War for the Planet of the Apes*, Andy Serkis is transformed into the primate leader Caesar via motion capture



Visual effects through the years

Here are some key moments in the history of movie visual effects

1973

In Michael Crichton's *Westworld* the lead character's 'robovision' is the first example of 2D CGI.

1976

The first 3D computer graphics are found in *Westworld's* sequel, *Futureworld*. The main android's head and hands are digitally created.

1977

The Death Star attack briefing scene in *Star Wars IV* sees the first example of 3D wireframe graphics.

1982

In *Tron*, the light cycle races were the first extensive 3D CGI sequences seen on the silver screen.



1985

Combining digital and live action, Pixar's *Young Sherlock Holmes* creates a stained glass warrior that leaps straight from the window to the ground.

1989

The first example of CGI water effects appears in *The Abyss* in the form of a morphing sea monster.





DESIGNING THE DALEKS

074

From the writer's room to the planet Skaro, Daleks were brought to life in the creative mind of Raymond Cusick. Design started from a script direction that read, "Standing in a half circle in front of them are four hideous machine-like creatures. They are legless, moving on a round base. They have no human features. A lens on a flexible shaft acts as an eye. Arms with mechanical grips for hands." The Daleks were born.

The arch-nemesis of the Doctor, Daleks are the destroyer of worlds. Their shared goal is to 'exterminate' the human race and anyone who stands in their way. Built from the unbreakable 'bonded polycarbide' called Dalekanium, these interstellar soldiers are feared throughout the galaxy.

Anatomy of a Dalek

Inside the most feared and deadly creatures in the universe

Directed-energy weapons

The Dalek's gunstick is reminiscent of today's laser directed-energy weapons, which produce a beam of concentrated electromagnetic energy or atomic/subatomic particles.

Mutated brain

A Dalek's more complex functions are controlled by a mutated organic brain.

Directional audio receptor

Located just behind the eye lens, this receptor enables a Dalek to detect which direction a sound is coming from.

Telescopic arm

Usually deployed to manipulate controls, the plunger on the end of this arm could also be used to suffocate or crush enemies.



Sensors

Much like the sensors in any modern-day car, a Dalek has collections of globular sensors on its exterior to monitor its surroundings and detect temperature changes and movement/proximity.

Kaled mutant

These octopus-like aliens originate from the planet Skaro. Normally reliant on their armoured exterior for protection, they are almost as deadly without it.

Doctor Who is well established within British culture - a Dalek featured on a set of Millennium stamps celebrating the 20th century

Hover-mode

Daleks are also equipped with anti-gravitational discs in order to levitate off the ground.

Science-fiction writer Terry Nation (pictured) first created the Daleks, before Raymond Cusick brought them to life



HEROES OF... TECHNOLOGY

Martin Cooper posing with the original model of the mobile phone he invented.



A life's work

The father of the mobile phone

1928

Marty Cooper is born on 26 December in Chicago, Illinois, to Ukrainian Jewish parents.

1950

Cooper graduates from the Illinois Institute of Technology with a degree in electrical engineering.

1954

After a brief stint at Teletype Corporation, Cooper is headhunted by Motorola and joins the company as an engineer.

1950-53

Serving in the US Navy, Cooper fights in the Korean War.

1972

As AT&T begin a project on the mobile phone, Motorola sets up a rival project and puts Cooper in charge.

He invented the cell phone

Meet Martin 'Marty' Cooper, a communications trailblazer

Sometimes invention is born out of necessity – sometimes it's born out of corporate rivalries. The latter is certainly more accurate when it comes to the invention of the mobile phone. There was so nearly a different name attached to this monumental creation, and the company its team worked for would have been AT&T. Instead, it was Marty Cooper's team at Motorola.

After getting his degree in electrical engineering from the Illinois Institute of Technology in Chicago and serving in the US Navy during the Korean War, Cooper found himself working for Teletype Corporation for a short while before moving on to Motorola in 1954. During his time there he was known as an innovator, working on projects that included the first radio-controlled traffic light system, patented in 1960, and the first handheld police radios, which were introduced in 1967. In fact, his contribution to the company was so great that he was made vice president and director of research and development in 1978. This promotion was probably in no small part due to his work earlier in the decade.

When Motorola found out that AT&T was putting a team together to invent the first mobile phone, the response was simple: the company was going to put together its own team and invent it first to avoid AT&T from dominating the market. Cooper was placed in charge, and they all got to work. Ideas were bounced around and prototypes made before, finally, they had created the Dynamic Adaptive Total Area Coverage phone, or DynaTAC. At 23 centimetres tall, it weighed 1.1 kilograms and it could be used for 35 minutes of talk time before the battery died, and it took about ten hours to fully charge. While it may not seem very impressive today, in the 1970s, that was a big deal.

Before it could be officially announced to the world that the phone had been invented, however, it needed to be tested. Cooper knew just how he was going to do so – a few days before the press conference, he stood on a street corner in New York City with the phone. He dialled a number and made the first ever call from a mobile phone. The man at the other end of the call was none other than Joel Engel, the leader of AT&T's rival project, the one that spurred Motorola into action in the first place. Now sure that it was in complete working order, Cooper unveiled the DynaTAC on 3 April 1973.

Work hadn't been finished, though – the next decade was spent refining the model, and the DynaTAC 8000x, a version suitable for consumers, went on sale in 1983. At \$3,995 it wasn't exactly the most affordable piece of equipment, but it was a success nonetheless, and mobile phones have now revolutionised the world. While these early models were only good for short conversations, the technology evolved into what we know today – mobile phones can now access the internet, provide entertainment and so much more.

THE BIG IDEA

From home, to cars to becoming a truly mobile phone

Marty Cooper hadn't set out to invent the mobile phone, but he was an expert in wireless communication technology. What he and his team designed was nothing short of revolutionary. While a sort of mobile phone had existed before, attached to cars, trains and other vehicles, this would be the first that could be carried anywhere. Over the ten years between making the prototype and launching the consumer version of the DynaTAC, it was refined and the battery was improved so that talk time increased to an hour, and there was enough storage for 30 phone numbers.



The DynaTAC 8000x was released in the US in 1983 and the UK in 1985

5 THINGS TO KNOW ABOUT... MARTY COOPER

1 29 years at Motorola

Cooper worked his way up to becoming vice president and director of research and development having working on the mobile phone project.

2 Working for the competition

Before joining Motorola in the 1950s and working against AT&T to invent the mobile phone first, Cooper had actually been employed by Teletype Corporation, an arm of AT&T.

3 Prize-winning inventor

Cooper has earned many awards in his time, including the Charles Stark Draper Prize from the US National Academy of Engineering and the Marconi Prize, both in 2013.

4 Wireless communication for life

After leaving Motorola in the 1980s, Cooper founded Cellular Business Systems, Inc. and then Dyna, LLC., both of which focused on aspects of wireless communications.

5 War veteran

Cooper served in the US Navy as a submarine officer during the Korean War, but he didn't get into radio technology until he began working at Motorola, a year after the war ended.

1973

The new DynaTAC is unveiled in New York City. To check it works, Cooper phones the lead engineer on AT&T's team.

1983

In the year the DynaTAC 8000x goes on sale, Cooper leaves Motorola and founds his own company, Cellular Business Systems, Inc.

1978-83

Working his way up through the ranks, Cooper becomes vice president of research and development at Motorola.

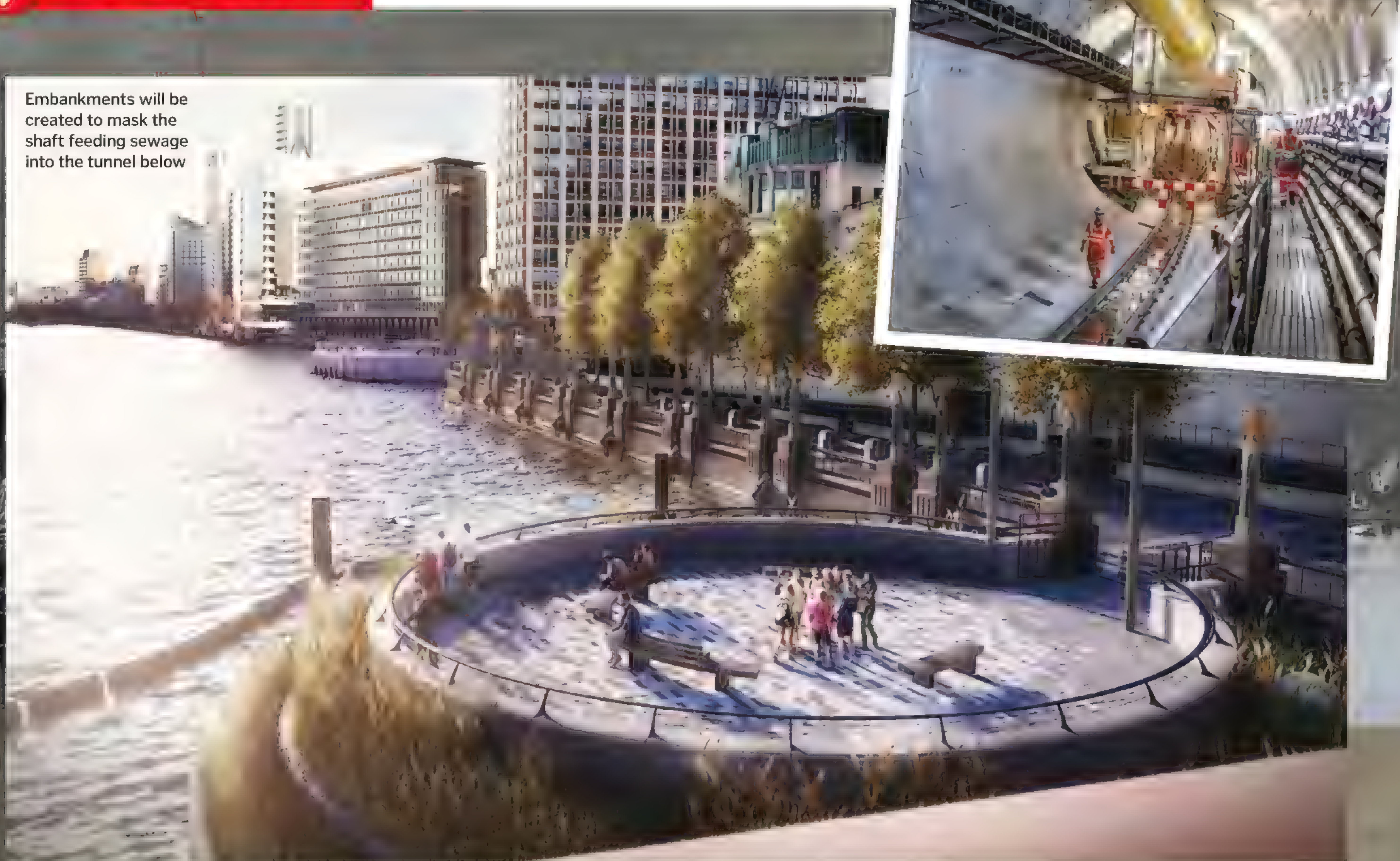
1986

Cooper sells his company to Cincinnati Bell for \$23m. He then founds another company with his wife, Arlene Harris, called Dyna, LLC.

"At 23 centimetres tall, it weighed 1.1 kilograms and it could be used for 35 minutes of talk time"



Embankments will be created to mask the shaft feeding sewage into the tunnel below



Explore London's super sewer

Discover the tunnel being built deep beneath the Thames River and how it's going to prevent poo from contaminating the water

Words by Scott Dufield

In the mid 1800s, London's Victorian sewer system was built to combat the growing outbreaks of cholera and typhoid fever that were killing thousands of Londoners. It was designed by chief engineer Joseph Bazalgette, used around 318 million bricks and spanned the entire city.

Although the Bazalgette sewer system has served the residents of London well over the past 150 years, it hasn't been without issues. Originally built to support the waste of 4 million people, the capital city is now home to over 8 million people and rising, putting

pressure on the city's sewers. Currently the sewers are contending with 1.25 million tons of human waste each day.

As a fail-safe to prevent sewage from spilling onto the streets of London, the current network of pipes is connected to several overspill pipes that deposit waste into the water of the Thames. As London's population continues to grow, millions of tons of waste contaminate the river's water.

It is this overspill design that has prompted Tideway, an engineering company, to create the Thames Tideway Tunnel. As an improved

4. Sewer connections

As sewage begins to fill the shaft, it will feed via connecting pipes to the central Thames tunnel.

5. To the pumps

Collected sewage will travel beneath the Thames until it reaches Abbey Mills Pumping Station downstream.

Cleaning up the Thames

How the new Thames Tideway Tunnel will prevent overflow from entering the river

2. Overflow
In the event of heavy rainfall and sewage overflow, the sewage will spill into newly constructed shafts rather than flow into the Thames.

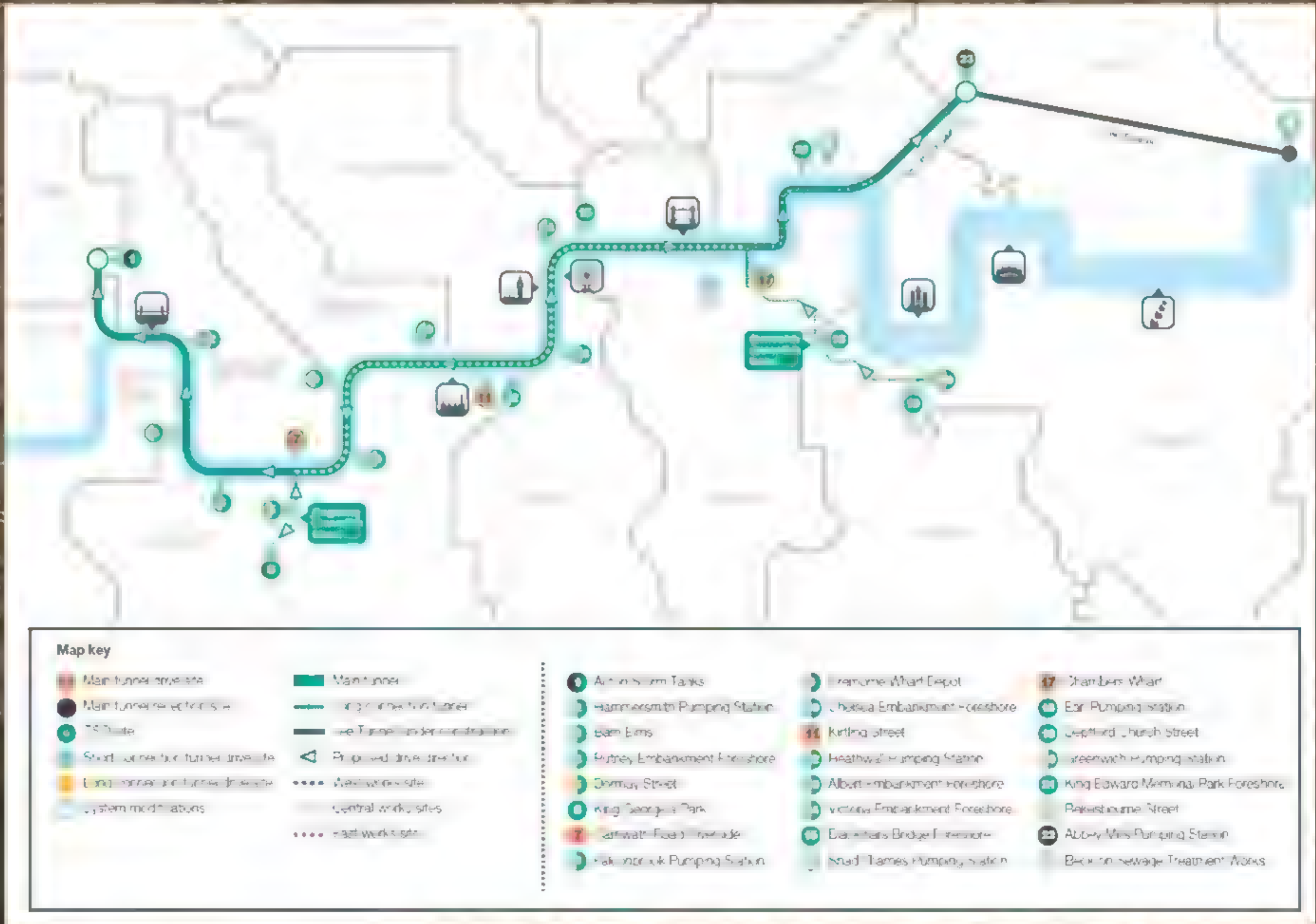
3. Deep shafts
Sewage will travel down and begin to fill deep shafts at various locations along the Thames.

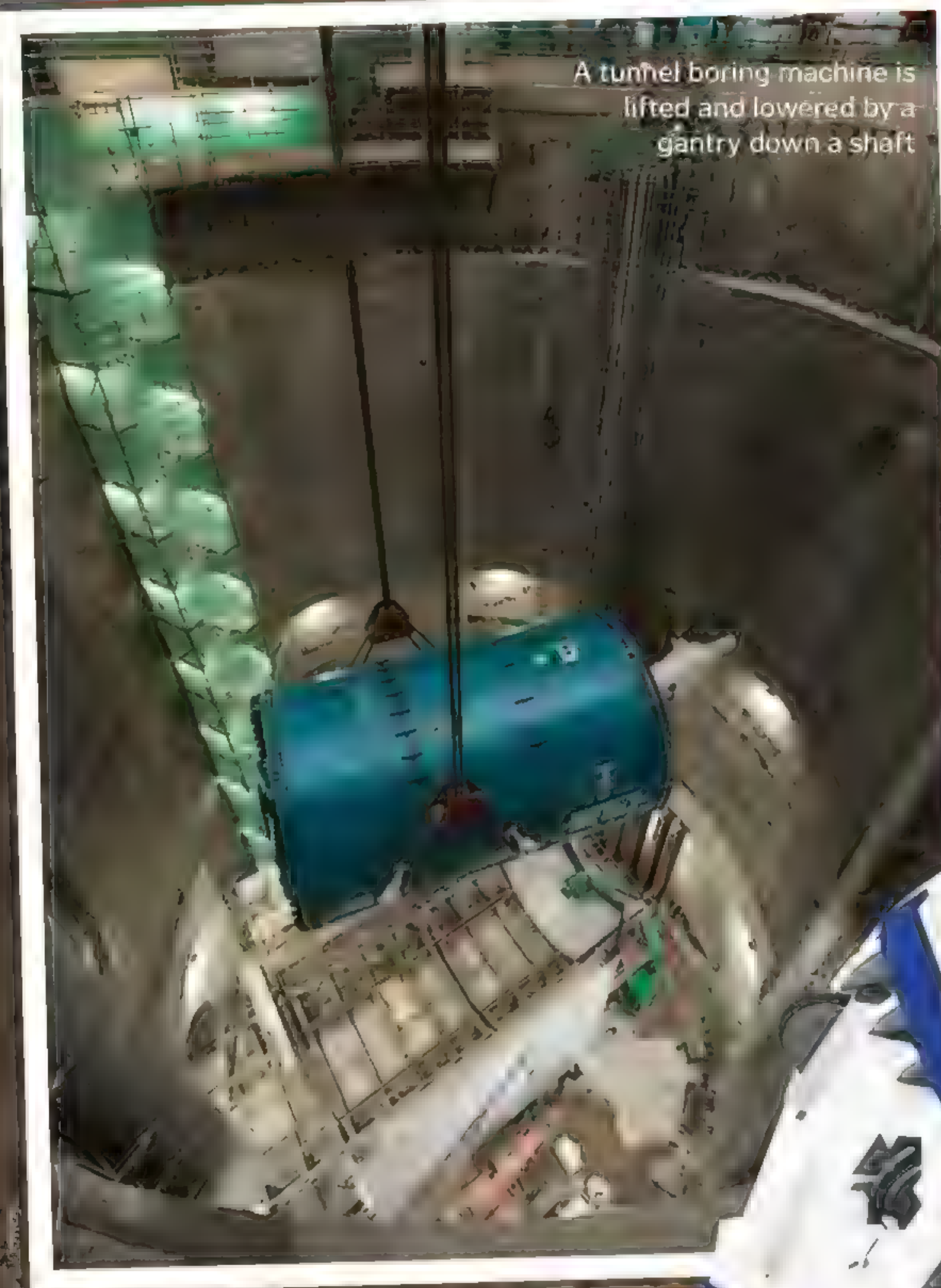
1. Current sewer system
London's current network of pipes deliver untreated sewage to treatment centres around the city.



Subterranean super sewer

The new tunnel's route takes it from one side of London to the other





A tunnel boring machine is lifted and lowered by a gantry down a shaft

Giant Thames worm

Officially known as a tunnel boring machine (TBM), this mammoth vehicle can cut through bedrock, clearing the way for the new super sewer under the Thames.

Propulsion

The TBM moves with the help of hydraulic rams that push against the newly placed tunnel ring, moving it forward.

Cutter head

Made of steel, this circular, 8m mouth of earth-cutting teeth rotates, breaking down soil and rock in order to carve out the tunnel.

In addition to the Victorian sewers, the new super sewer is a prime example of engineering precision.

Beginning at Acton Storm Tanks in Ealing, the 25-kilometre-long tunnel will burrow beneath and follow the Thames until reaching Abbey Mills Pumping Station in Newham, London. Sewage collected throughout the tunnel will be sent down the Lee Tunnel, reaching its final destination at the Beckton Sewage Treatment Works.

In order to shape the Thames Tideway Tunnel, massive machinery has been brought in to carve into the rock deep below the river. Known as a tunnel boring machine (TBM), this burrowing behemoth pushes its way through bedrock, shaping the tunnel as it goes. What lies in the wake of the TBM's tunnelling force is tons of displaced rubble. Continually feeding through the belly of the metal beast, excavated material or slurry is carried on conveyor belts back to the surface.

Construction of the tunnel will create 4 million tons of rock and rubble that will need to be removed. Tideway is utilising the Thames to transport the material to landfill sites, via barges that can carry the equivalent of 50 heavy goods lorries. The rubble will then be used to cap off landfill sites, which will then be turned into nature reserves.



48 hours

The time taken to empty the tunnel when full

7.2 metres

The width of the tunnel

25
kilometres

The complete length of the Thames Tideway Tunnel

Screw conveyor

Broken-down rock and sediment travels up the 18m screw conveyor and is deposited on a conveyor belt.

600
Olympic-sized swimming pools

The Thames Tideway Tunnel's storage capacity is equivalent to

Conveyor belt

Debris is delivered onto a conveyor belt travelling the length of the constructed tunnel and is taken up the shaft to be removed and taken away from the site.

Erector arm

Each segment of the tunnel ring is lifted by a hydraulic arm and vacuum and secured in place.

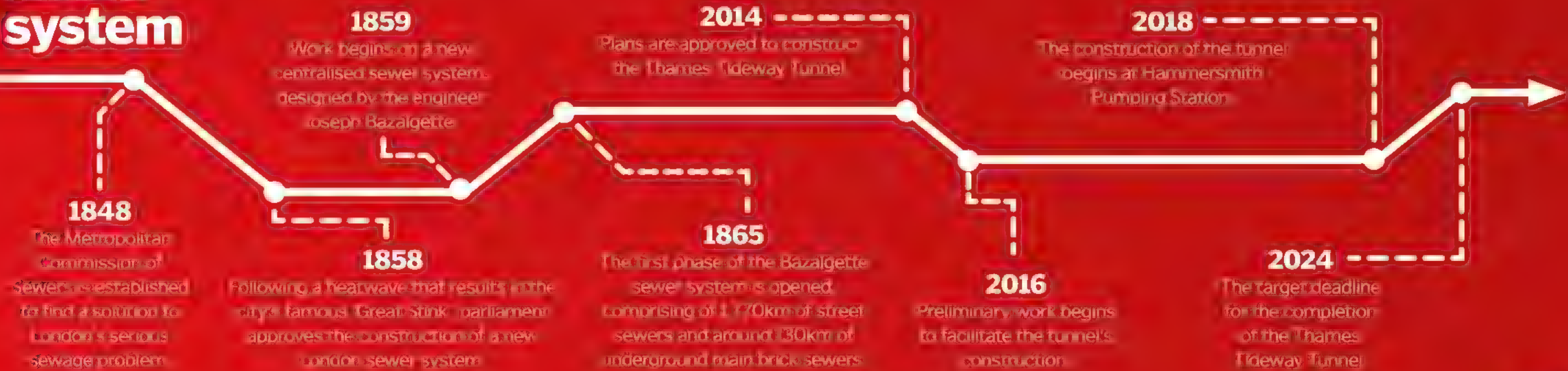
£4.2
billion

Estimated cost to construct the new tunnel

35-65
metres

The depth below the ground the Thames tunnel will run

Constructing London's sewer system





The Belvedere Riverside Resource Recovery plant in London processes almost 600,000 tons of waste and generates power for 66,000 homes



Flames roar to over 1,000°C inside a household waste incinerator at an energy recovery unit in France

What's inside a waste incinerator?

These hulking machines burn hot enough to melt metal and send rubbish up in smoke

The UK alone produces approximately 220 million tons of waste annually, a figure that contributes to a global yearly total that hit 1.3 billion tons in 2017. Experts have predicted that this number could reach 2.2 billion by the year 2025 as urbanisation continues to increase. All of this waste has to be collected and handled safely, and one method that is commonly used is incineration.

Running at around 750 degrees Celsius, incinerators come in a variety of designs (including those fitted with a rotary kiln), but they all share the same purpose – to safely destroy waste and treat the by-products of this process in order to mitigate the chances of potentially hazardous materials being released into the atmosphere.

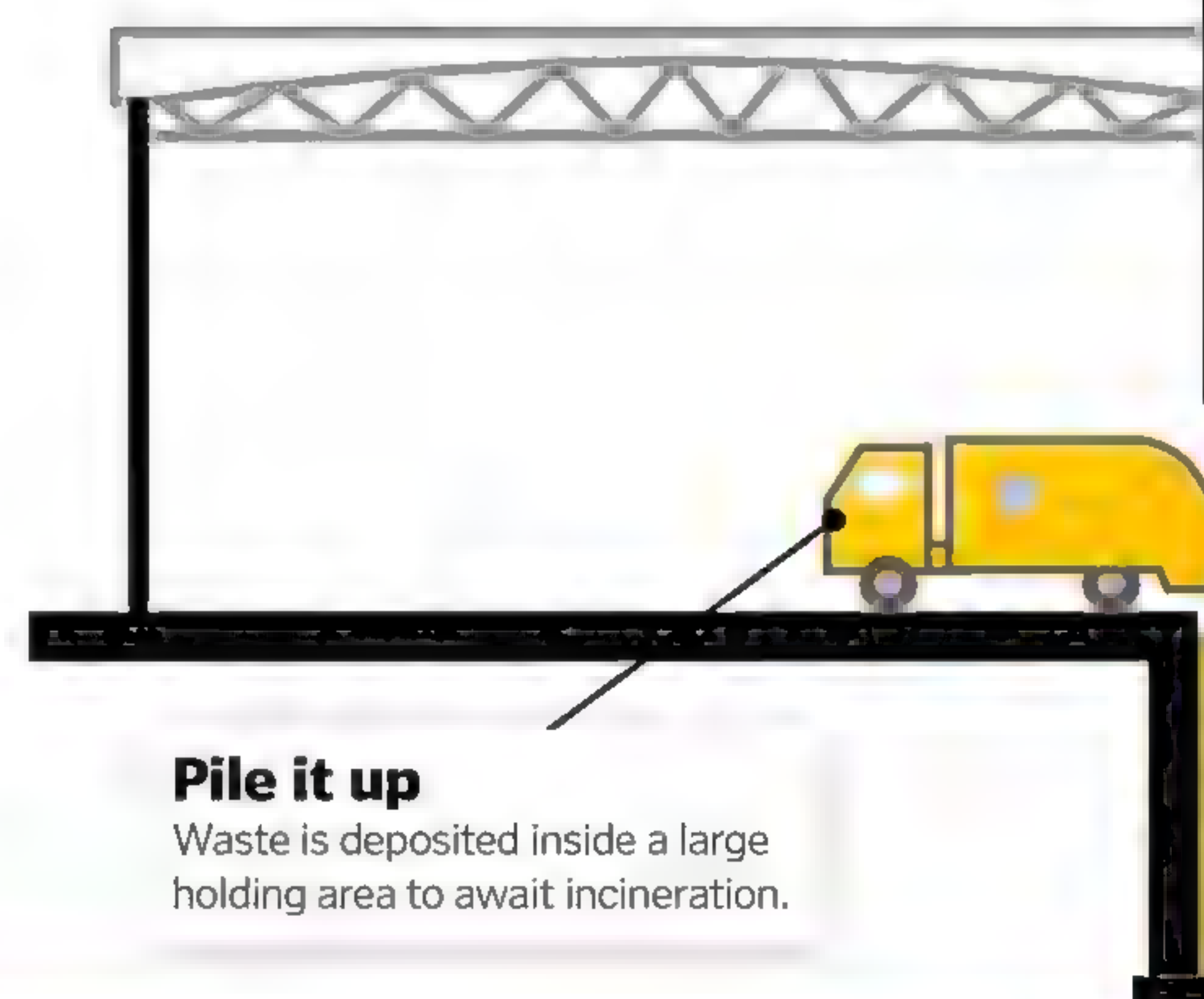
This is achieved by first burning the municipal materials collected and then inspecting the ash produced as a result. This ash comes in two

forms: fly (or flue) and bottom ash. The latter is the least dangerous as it clings to the searing sides of the incinerator. This type of ash is inspected with a magnet to retrieve any valuable metals for recycling. However, the finer variety of fly ash can be unsafe to expel from chimneys, as it often contains gaseous traces of heavy metals such as lead and mercury. Fly ash is therefore passed through a scrubbing device to treat and remove any harmful substances from the exhaust before it is released.

There are currently 44 waste incinerators in operation in the UK, and many environmentalists are concerned about the emissions released from incinerators. Another disadvantage is the high cost required to keep an incinerator working, but with plans in place to double the number of these rubbish burners in the UK, it seems that waste incineration will continue to be used in the near future.

Your burning question

What happens to our rubbish when it's incinerated?



Pile it up

Waste is deposited inside a large holding area to await incineration.



Dubai has set itself a target of reducing its landfill waste by 75 per cent

Dubai's mega incinerator

In January 2018 Dubai announced its intentions to construct what will be the biggest waste-to-energy plant on Earth. Scheduled to be built in Warsan, United Arab Emirates, the plant will be capable of processing 2 million tons of waste a year, which makes up 60 per cent of the waste produced by the city. This will generate enough electricity to power approximately 120,000 homes in the surrounding district.

Waste collected from around Warsan will be burned at a temperature of 1,200 degrees

Celsius in order to thermally treat any potentially dangerous gases contained within the waste, before any remaining fly ash can be released via the plant's chimney.

A potential rival to this superplant has been given the green light in Shenzhen, China. Located in China's southeast, Shenzhen's 20 million inhabitants produce 15,000 tons of waste a day, a third of which will be incinerated within the city's new energy plant upon completion in 2020.

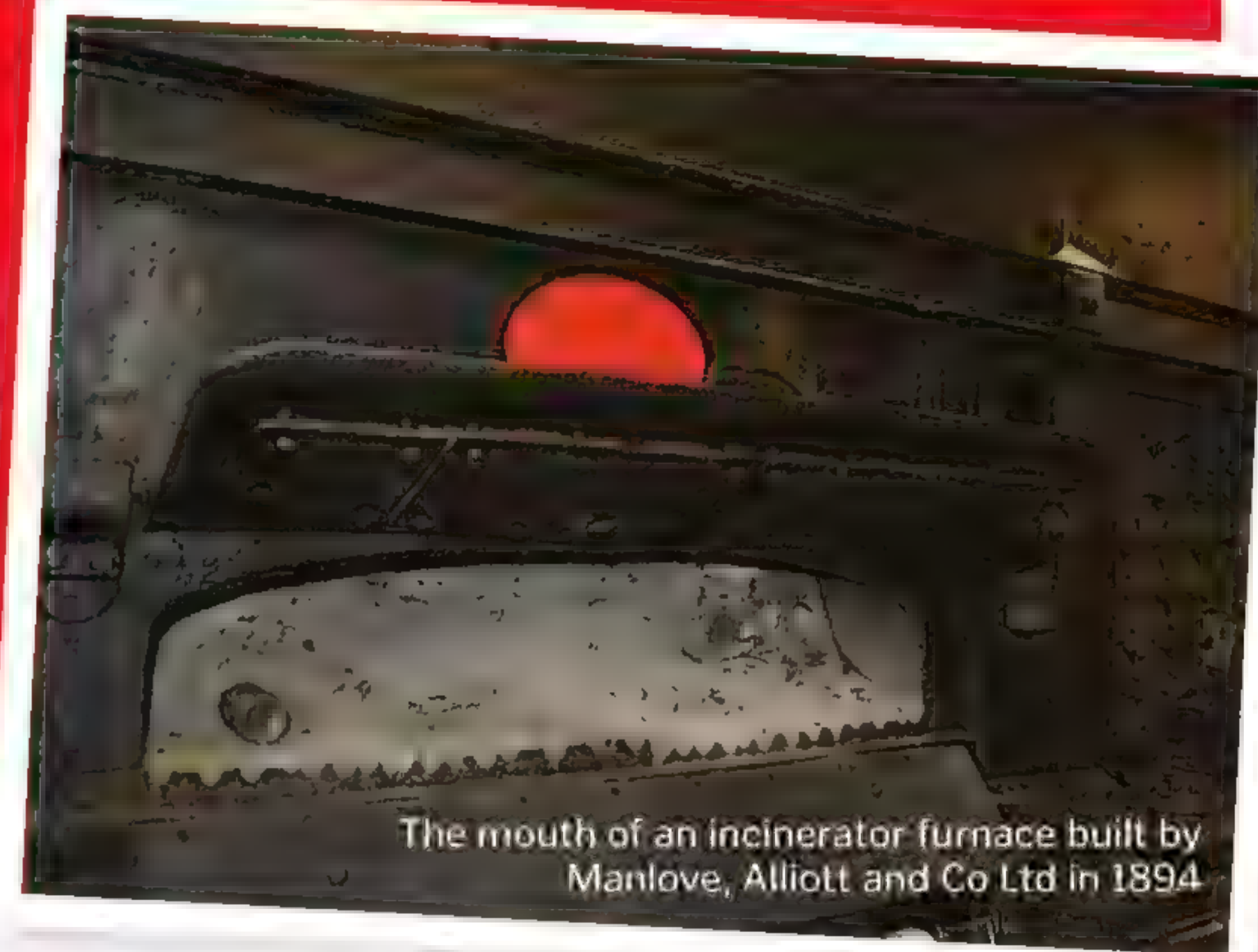
Alfred Fryer - incendiary pioneer

Born in Yorkshire, England, in 1831, Alfred Fryer would one day patent an idea that would revolutionise waste management in the industrialised West, but first he would take an unusual - and rather sweet - career path.

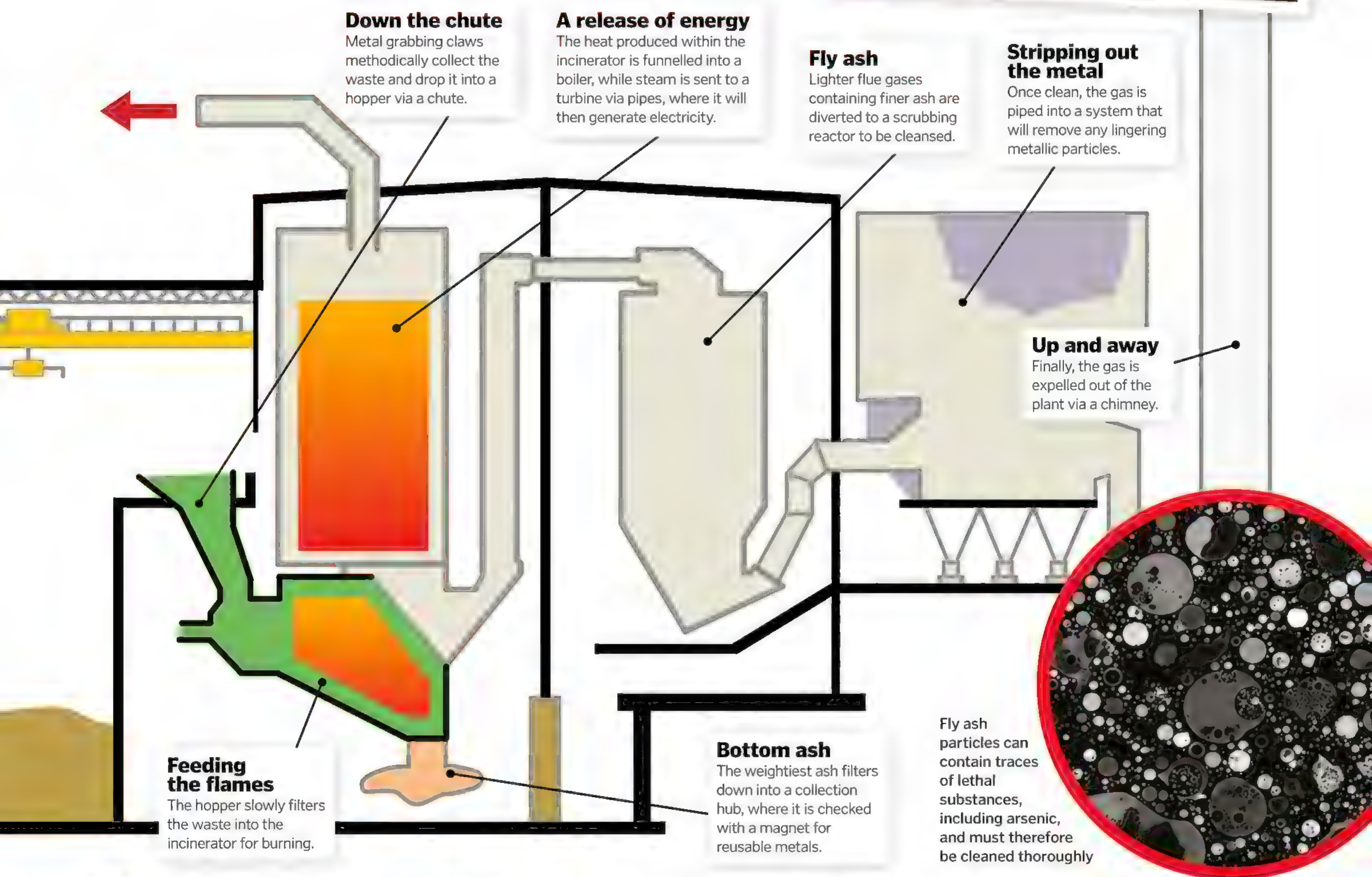
Appointed head of the Manchester-based sugar refinery Fryer, Benson and Forster while in his early 30s, in 1865 Fryer invented a machine known as a 'concretor' designed to solidify sugar

cane juice before it was shipped abroad. He then followed this creation up in 1874 while working at Manlove, Alliott and Co Ltd with a patent for a 'destructor', which would later be recognised as the first ever commercial waste incinerator.

A father of four, the inventive Fryer often conducted business in far-flung locations, and he visited destinations including Egypt and Palestine prior to his death in Cheshire in 1892.



The mouth of an incinerator furnace built by Manlove, Alliott and Co Ltd in 1894



50% The UK is aiming to recycle half of its household waste by 2020.

330m tons Annual disposal capacity of the world's waste-to-energy plants.

1874 The year in which the UK's first waste incinerator was built.

2kg The amount of rubbish each person in the US produces every day.

80-85% Amount of solid mass that an incinerator removes from waste.

2,450 Number of waste-to-energy plants currently in operation globally.

1.2% Decline in packaging waste recycling or recovery in the UK from 2016 to 2017.

267,000m² Floor space of the waste-to-energy plant set to be opened in Shenzhen, China.

267,000m²

THE FUTURE OF MEDICINE Electroce

Should we ditch drugs to make way
for an electrical alternative?

Words by **Scott Dutfield**

YOU KNOW? In the future, electroceutical implant devices could be less than 100 nanometres wide [as small as a virus]

uticals

A great many of us often don't think twice about popping a pill to treat a chronic condition. The most up-to-date data from the European Union suggests around 49 per cent of people within its 28-member countries aged 15 and over use prescribed medicines. However, with the introduction and development of bioelectronic technologies, pills could soon be a thing of the past for some conditions.

Implanted electrical devices that work to repair, replace or restore parts of our bodies have been employed by doctors since the 1950s. The first cardiac pacemaker was implanted in a 43-year-old male back in 1958 to combat his cardiac arrhythmia. Since then devices have been created to restore senses such as hearing and sight and regulate insulin for those suffering from diabetes. However, in recent years 'electroceutical' devices have been making waves as a treatment for chronic conditions.

Fundamentally, the principle of electroceuticals is to emit a low-energy electrical pulse to stimulate different nerves in the body to aid the reduction of symptoms for an array of physical conditions such as epilepsy and rheumatoid arthritis. Recent investigations into externally worn devices have even suggested that they might be a treatment solution for mental health conditions such as depression and anxiety, an incredibly exciting possibility.

One of the biggest downfalls of chemical medication are the potential side-effects they can cause. These side-effects mostly occur due to pharmaceuticals affecting not only the intended target but several organs when they enter the body. Electroceutical treatments offer a more accurate approach as they can focus on



Vagus nerve stimulator (VNS) devices are implanted under the skin to treat epilepsy

particular nerves connected to specific organs, limiting the number of side-effects. For example, one of the most widespread uses of electroceuticals is treating epilepsy with a vagus nerve stimulation (VNS) device. Epilepsy is a condition whereby nerves 'fire off' abnormally when sending signals to different parts of the body, resulting in seizures of varying degrees. The condition affects more than 500,000 people in the UK alone. VNS devices are able to help manage these symptoms through artificial electrical stimulation.

Implanted beneath the skin and hooked onto the vagus nerve at the neck, a generator, which resembles that of a pacemaker, creates electrical pulses that feed through a lead to the nerve at regular intervals. This stimulation regulates the electrical signals through the vagus nerve into the brain, reducing seizures. Should a seizure occur, or even a warning of an oncoming episode, a handheld magnet can be waved over the implant's generator to produce more impulses, preventing or reducing its longevity.

These VNS devices are not a cure for a condition, but they greatly relieve the symptoms.

The same technology has also been used to treat those with rheumatoid arthritis, a long-term autoimmune disease that causes inflammation at the joints. A VNS device can send electrical impulses along the splenic nerve to stimulate the spleen, thereby reducing its immune response and any inflammation.

The potential for electroceuticals to become commonplace treatments is vast, but finding the right nerve circuitry can be a tricky task. There are 12 pairs of cranial nerves and around 86 billion neurons in the brain alone, each delivering electrical messages through nerves around the body.

In order to use nerves as a method of treatment, scientists must first locate which nerve carries which message and to where around the body. Brain mapping is a way of creating a road map of the mind to reveal all the avenues through the body. There are several methods currently used to map the brain, one of

which is electromyography, which measures the electrical activity in the brain through electrodes placed around the head. However, each of our brains is wired differently, with the exception of major nerves such as the vagus

nerve. Therefore it is difficult to create universal electroceuticals, and thus far a complete map of the brain's complex network of neurons is yet to be visualised.

Though VNS devices seem to hold the monopoly on bioelectronics, recent discoveries are shedding light on the potential for electroceuticals to repair

physical damage within the body too. Earlier this year researchers at the Northwestern University and the University of Washington, US, created an implantable wireless device that speeds up the regeneration of damaged nerves.

The device (trialled on rats) emits regular pulses of electricity to damaged sciatic nerves to accelerate nerve growth and enhance muscle control and recovery. Consisting of a thin disc that wraps around nerves, the stimulator is activated wirelessly by a transmitter outside the body. This technology is designed to only work for a specific amount of time during the healing process. Engineers use materials that allow it to biodegrade and be absorbed into the body, preventing another extraction surgery.

Of course, electroceuticals are not the answer to all of our medical problems; bacterial diseases, for example, cannot be treated using these electrifying methods. Electroceutical technology is still in its medical infancy in terms of its general use, and its long-term effects have yet to be determined.

"Electroceutical devices have been making waves as a treatment for chronic conditions"



Electrical pulses from a VNS device are carried through a thin wire connected to a generator close to the skin



New devices built to repair nerves will dissolve once the healing is completed



Electromyography uses electrodes to map the brain's neural pathways

Wearable tech

Meet the man behind Modius – the electro-stimulation headset that tricks the brain into thinking you're working out

Dr Jason McKeown is the CEO and co-founder of Modius Health. Here he explains the science behind their new headset and what the future may hold for wearable electronic medicine.

How does Modius stimulate weight loss?

The hypothalamus controls all elements of metabolism, so that's your metabolic rate, core temperature, your appetite even and all of your hormone profile. Your vestibular nerve connects to that, so we used electricity to stimulate the nerve, similar to the way implants do. We believe that your vestibular nerve picks up physical activity, so it's almost a reference point to how active you are. Say you're a bear hibernating; there is zero physical activity, so your vestibular input is zero because you're just lying there, sleeping. So the metabolism shifts slightly to store fat. It's a very old evolutionary thing that guides metabolism to how physically active we are. So basically, we kind of hack that connection to some degree and activate it over and over again using electrical stimulation, and that's how we developed this headset that you can wear for an hour to repeatedly stimulate that part of the brain.

Why doesn't this form of stimulation affect other brain functions?

The vestibular nerve itself only has projections

into the areas [of the hypothalamus] that physical activity has any reference to. It's almost like a filter that works by filtering areas that are only relevant for things that connect with physical activity.

What is the future of Modius Health and wearable bioelectronics?

What we can do isn't limited to weight loss. That just happened to be the first thing we looked at. So we are actually looking in the mental health space, at anxiety and depression also. We have also started trials in migraines and epilepsy. People think we are just a weight loss company, but the technology is actually a delivery method. It delivers stuff to the deep part of the brain, that's the kind of cool part of it. Once you know you can deliver something into the brain it's really up to you.

Is this technology something we might see available on the NHS?

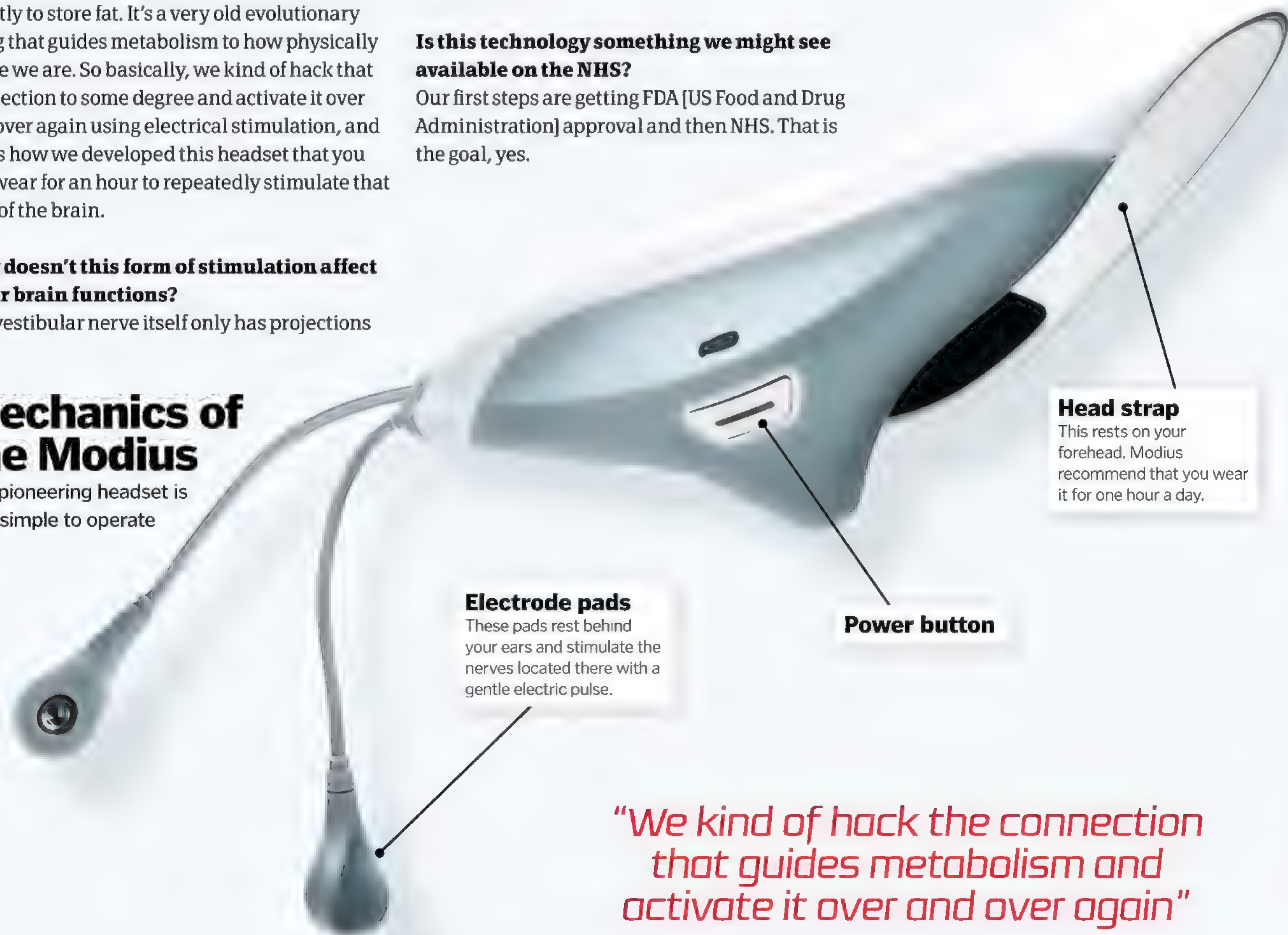
Our first steps are getting FDA [US Food and Drug Administration] approval and then NHS. That is the goal, yes.



Dr McKeown founded the Belfast-based company Modius Health in 2013

Mechanics of the Modius

This pioneering headset is very simple to operate



"We kind of hack the connection that guides metabolism and activate it over and over again"



SPACE

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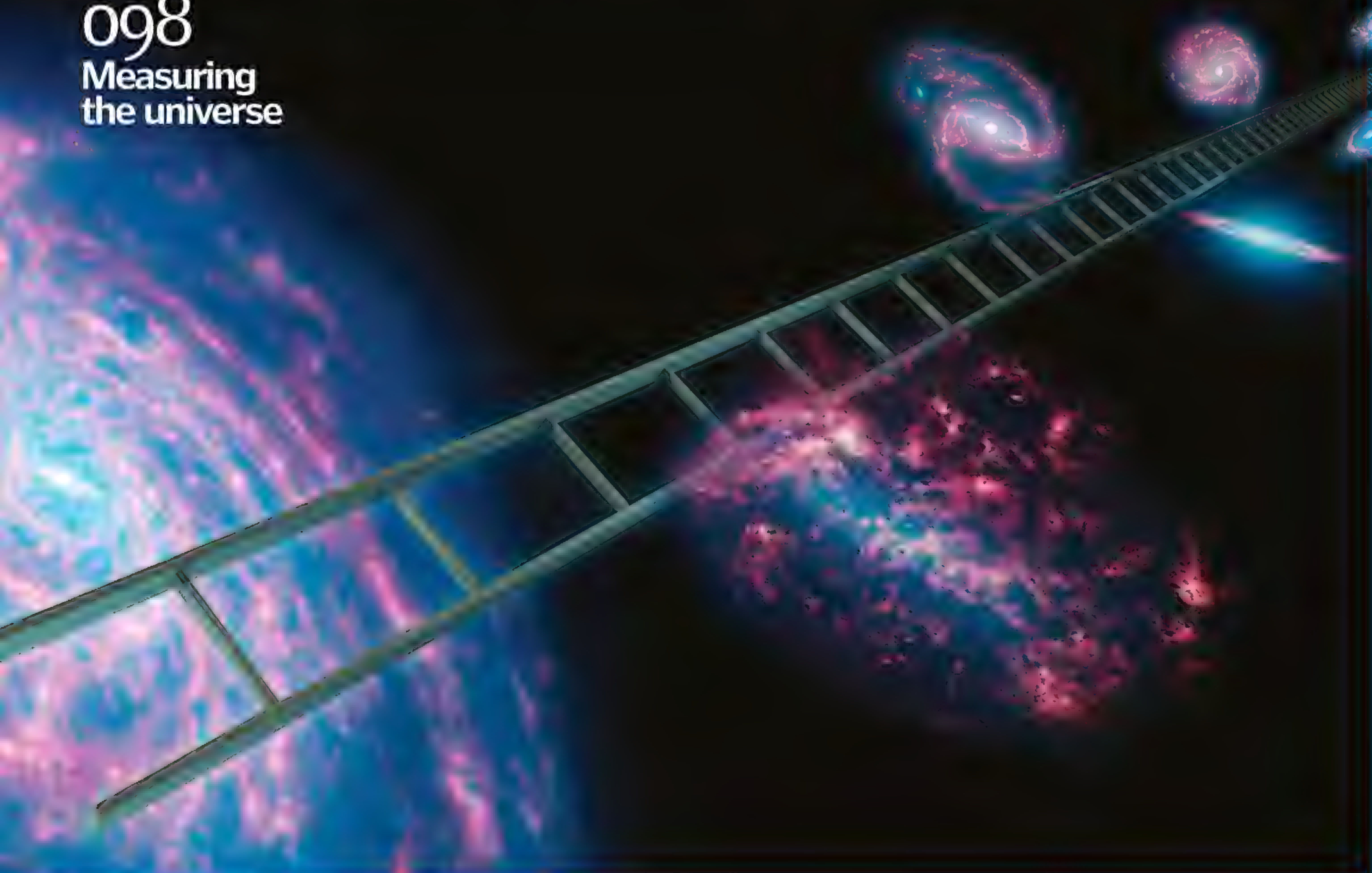
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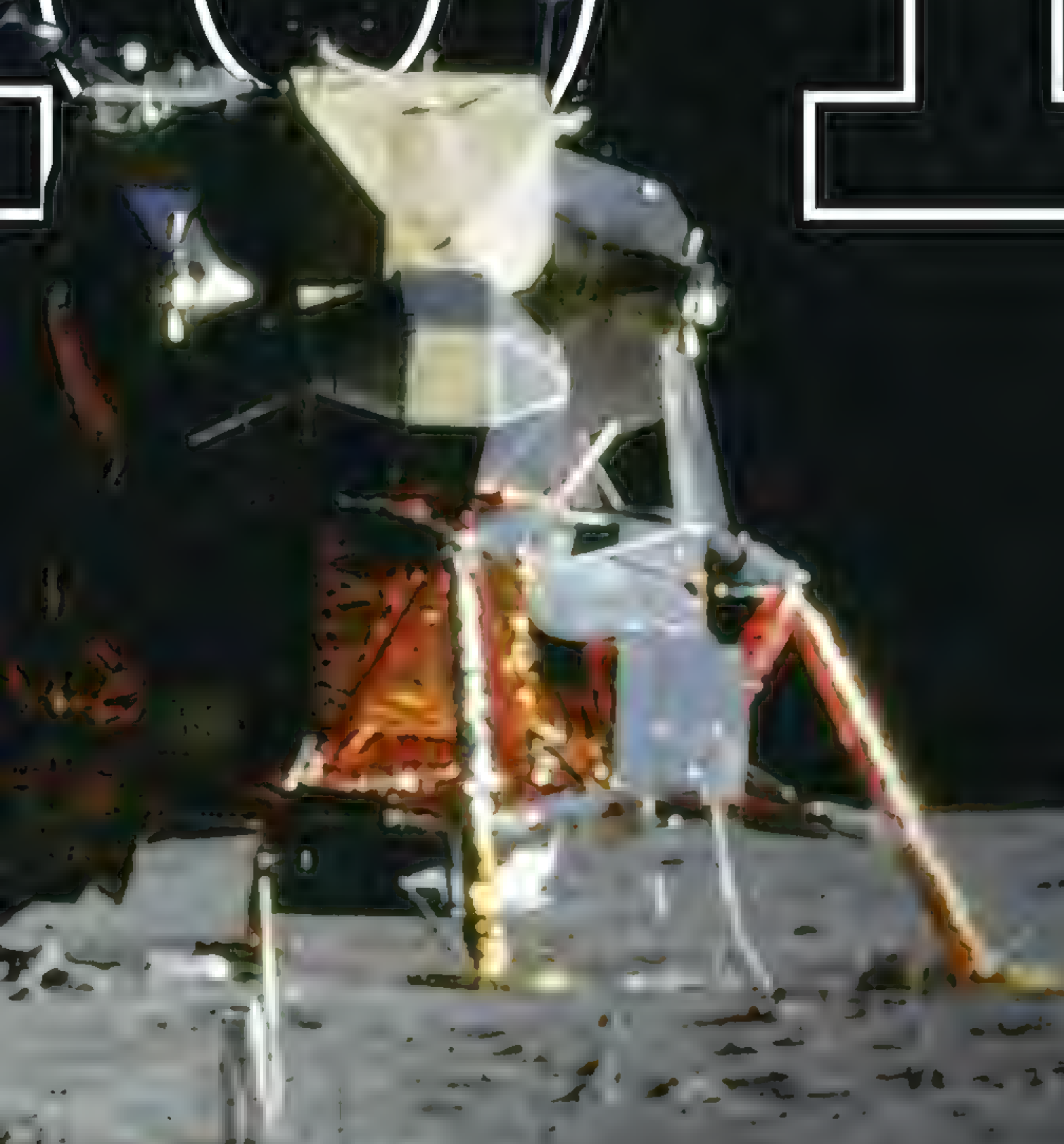
SCIENCE SECRETS OF APOLL

**Incredible feats of ingenuity made the 1969
Moon landing possible – many that you
probably never knew about**

Words by Andrew May



011



Fifty years ago last July, Apollo 11 carried three astronauts – commander Neil Armstrong, Command Module pilot Michael Collins and Lunar Module pilot Edwin ‘Buzz’ Aldrin – all the way to the Moon. Once there, Armstrong and Aldrin went down to the surface for a history-making moonwalk, while Collins stayed in lunar orbit. Then they returned to Earth, splashing down in the Pacific some eight days after they left the planet.

Even from today’s perspective, the Moon landing was an astonishing achievement, and in 1969 it pushed the limits of what was technologically possible. Yet the science behind it was 300 years old, going all the way back to Isaac Newton’s law of gravity, first formulated in the 1660s. That may sound counterintuitive, because gravity is what holds us to the surface of the Earth. But if you toss a ball up in the air, it travels higher and higher as you launch it with increasing speed. Newton realised the

same trend continues out in space. The faster something leaves Earth, the further it travels before coming back. Give it enough speed – sideways as well as up – and it will go into orbit. Even more speed, and it can reach the Moon.

The first humans to reach the Moon – going round it, rather than landing – were the crew of Apollo 8 in December 1968. They understood the science as well as anyone. As one of them, William ‘Bill’ Anders, said on the journey home, “I think Isaac Newton is doing most of the driving right now.” That’s not Newton himself, of course, but his law of gravity. It’s the reason spacecraft don’t need to run their engines all the time, just in short ‘burns’ to get up to the right speed, and then gravity does the rest.

“I think Isaac Newton is doing most of the driving right now”

Using the world’s biggest rocket

The key to getting a spacecraft to the Moon is giving it enough speed – around 11 kilometres per second – to carry it all the way there before it falls back to Earth. The Apollo spacecraft weighed close to 50 tons, so accelerating all that mass to the necessary speed required a lot of energy. The solution: the 111-metre-tall, three-stage Saturn V. Designed by the German-American rocket scientist Wernher von Braun, it remains to this day the largest, most powerful space launcher that has ever flown.

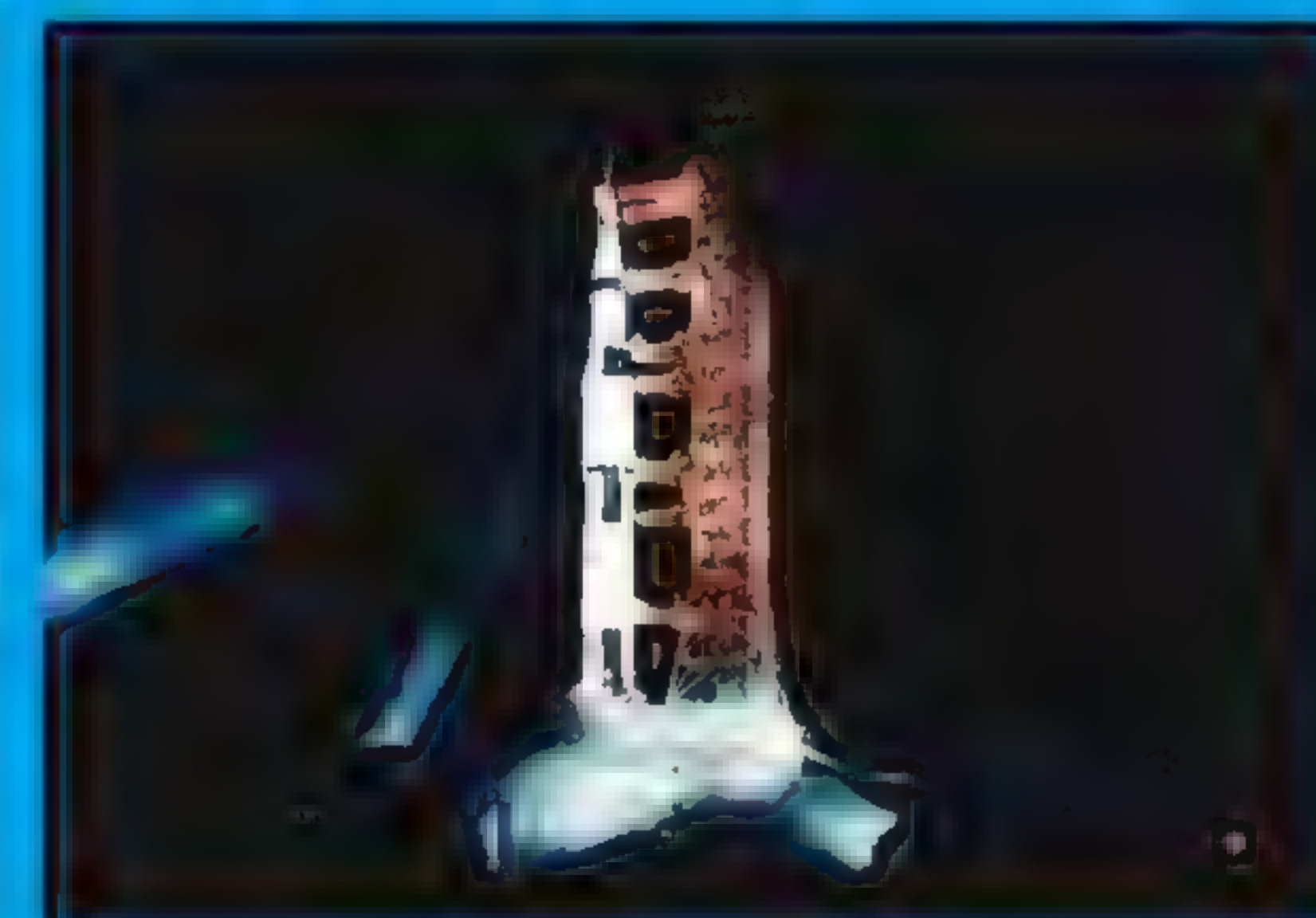


The Saturn V’s main engines tower over its designer, Wernher von Braun

Launching precisely on time

One of the most dramatic features of any space mission is the pre-launch countdown. But it’s not there simply to add edge-of-the-seat excitement for people watching – it’s to make sure all the necessary tests and preparations are done at the right moment and in the correct order. It’s also important to hit the launch window – a short period of time within which the launch has to take place. Missing it means postponing the launch until another day.

Once again, the launch window is all about science. The Earth is rotating and the Moon is moving in orbit around it, so everything has to line up just right for the launch to be successful. There are practical considerations too, such as making sure there will be a good line of communications between the spacecraft and the ground at critical moments.



Apollo 11 during a night-time countdown test a few days before launch

©NASA

©NASA

Combining two spaceships into one

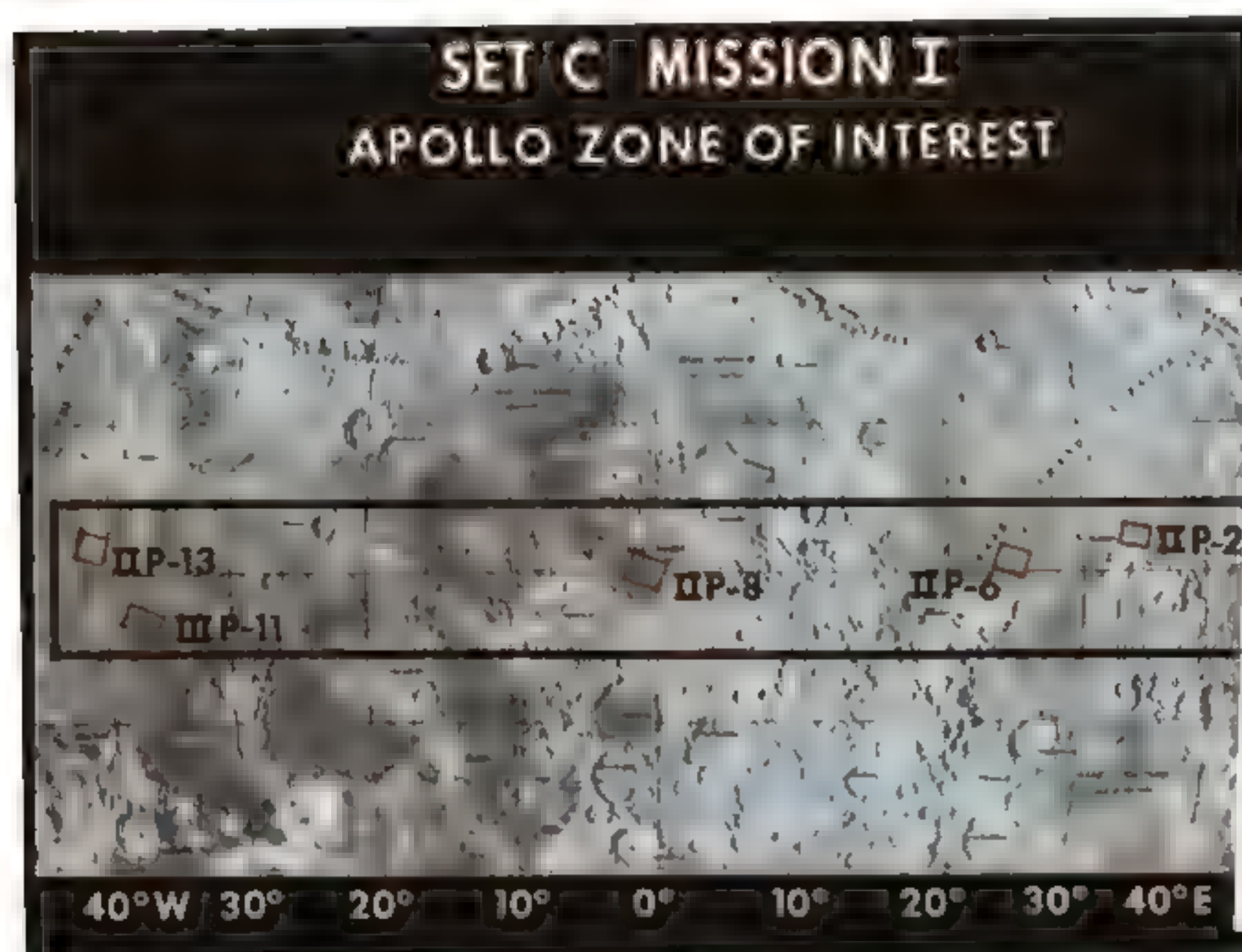
When NASA first conceived the Apollo project at the start of the 1960s, it was assumed the whole spacecraft would land on the Moon and then take off again to return to Earth. But that's really not very efficient. The amount of fuel a rocket needs increases with mass, and if you do things this way you're lifting more mass off the Moon than you need to. You can save fuel by going down to the surface in a separate landing vehicle specially designed for that task. So Apollo effectively became two spacecraft in one: the Command Module (CM) to get to and from the Moon, and the Lunar Module (LM) for the landing itself.



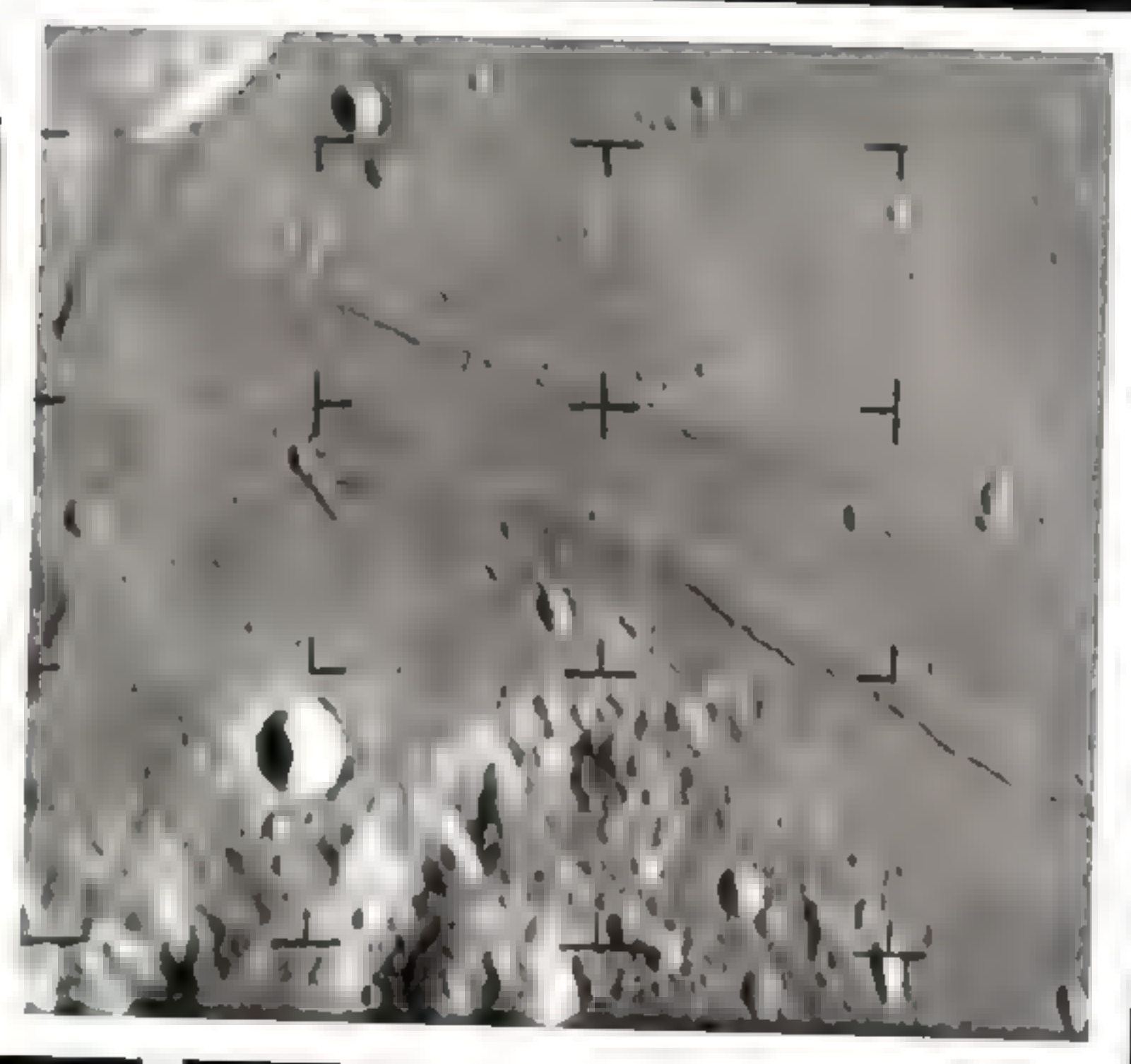
The Lunar Module starts its descent to the Moon, as photographed by Collins in the CM

Choosing the right landing site

Apollo 11 headed for a spot in the southwest of the Moon's Sea of Tranquillity – a spot now known as 'Tranquillity Base'. NASA put a lot of thought into a suitable site, coming up with a shortlist of five options. These were all close to the lunar equator, as that provided the least risky trajectory for the spacecraft. Other requirements were for flat, relatively uncratered terrain and good visibility during the approach. These factors were assessed using reconnaissance photos taken by unmanned Ranger and Surveyor probes.



Landing options were all near the Moon's equator – IIP-6 is Tranquillity Base



A reconnaissance photo of the area around Tranquillity Base, taken by Ranger 8 in 1965



Apollo 11's flight path

Splashdown

Date: 24 July 1969
Time: 16:50:35

Finally the SM is discarded, leaving just the CM to splash down in the Pacific Ocean.

Lift-off

Date: 16 July 1969
Time: 13:32:00 UTC

The three-stage Saturn V rocket launches Apollo 11 from the Kennedy Space Center in Florida.

Translunar injection

Date: 16 July 1969
Time: 16:22:13

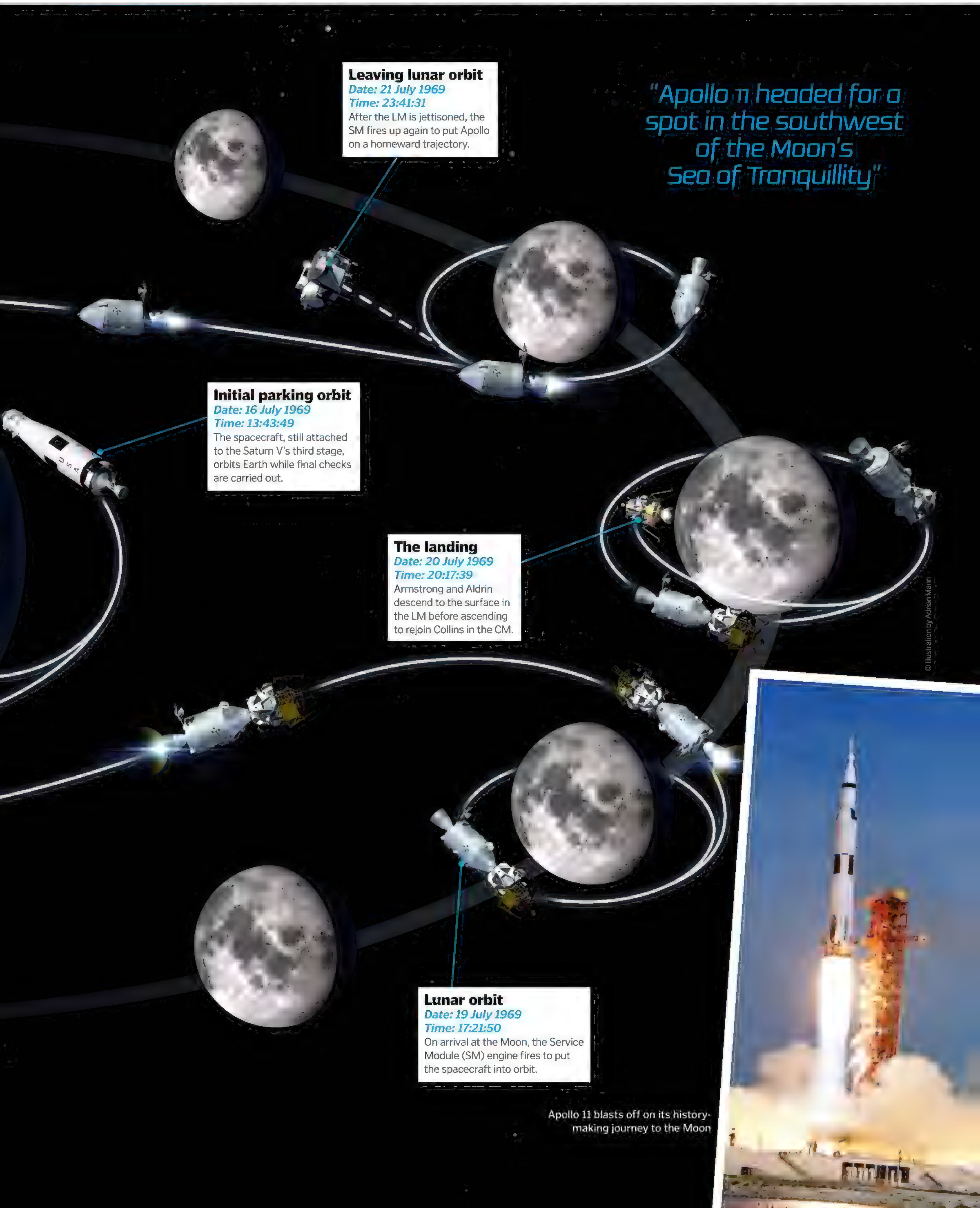
The third stage fires up again, putting Apollo on a trajectory that will take it to the Moon.

Linkup with Lunar Module

Date: 16 July 1969
Time: 16:56:03

The Command Module (CM) docks with the Lunar Module (LM) as the empty third stage is jettisoned.

DID YOU KNOW? The Apollo guidance computer contained 12,300 transistors. Your smartphone has over 1 billion of them



Leaving lunar orbit
Date: 21 July 1969
Time: 23:41:31
After the LM is jettisoned, the SM fires up again to put Apollo on a homeward trajectory.

"Apollo 11 headed for a spot in the southwest of the Moon's Sea of Tranquillity"

Initial parking orbit
Date: 16 July 1969
Time: 13:43:49
The spacecraft, still attached to the Saturn V's third stage, orbits Earth while final checks are carried out.

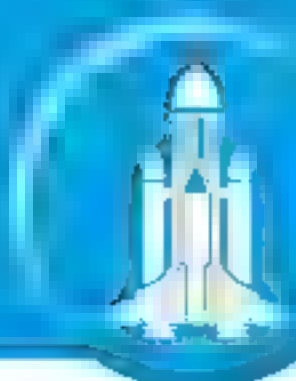
The landing
Date: 20 July 1969
Time: 20:17:39
Armstrong and Aldrin descend to the surface in the LM before ascending to rejoin Collins in the CM.

Lunar orbit
Date: 19 July 1969
Time: 17:21:50
On arrival at the Moon, the Service Module (SM) engine fires to put the spacecraft into orbit.

Apollo 11 blasts off on its history-making journey to the Moon



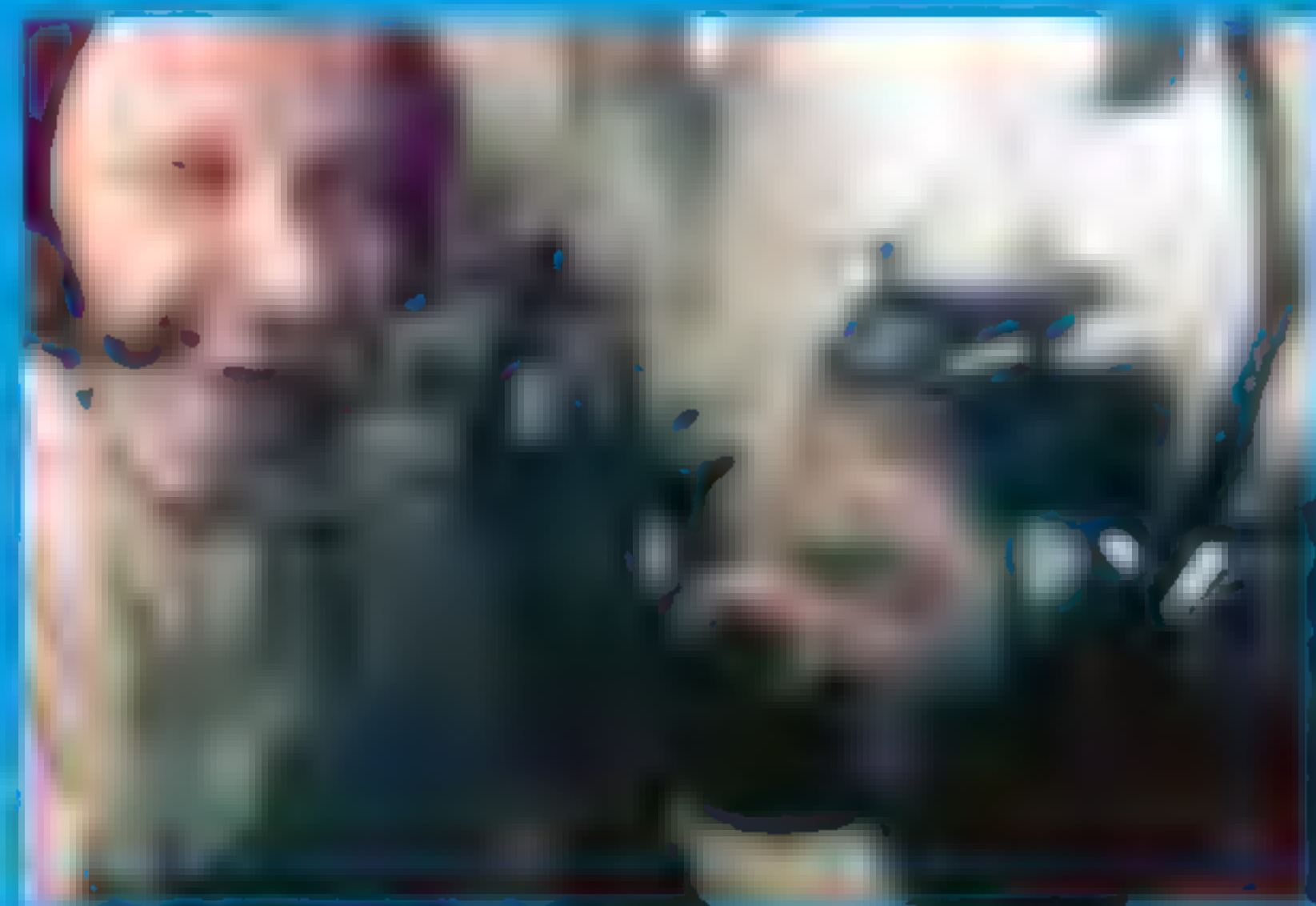
© Illustration by Adrian Mann



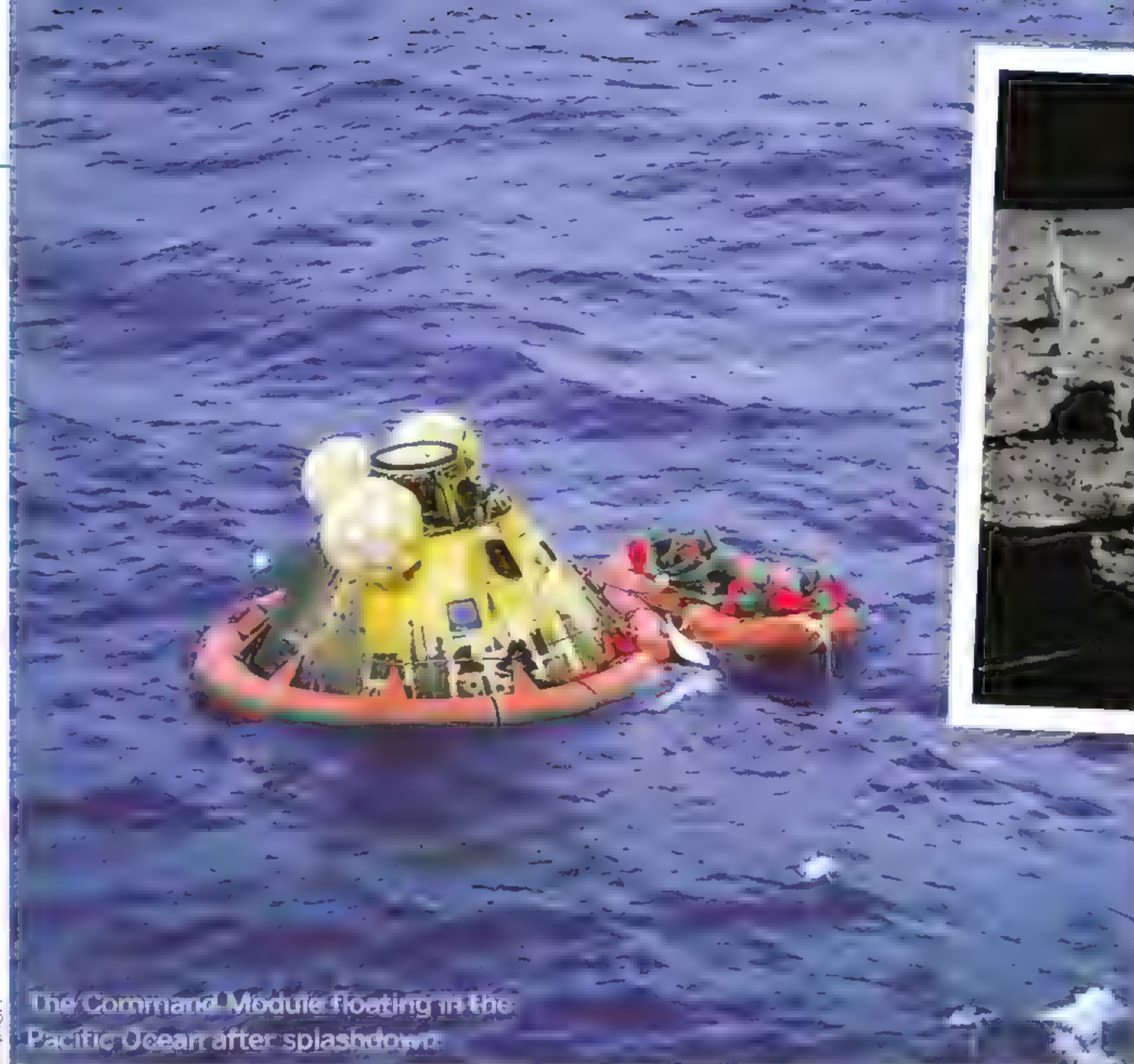
What happened to gravity?

We've seen how gravity is the main driving force in getting to the Moon. Yet one of the most familiar features of spaceflight is the 'zero-g' environment – the way astronauts lose all sensation of weight. How do you reconcile these two facts? As paradoxical as it sounds, the second follows from the first. When an object moves freely in a gravitational field – whether it's falling to Earth, or in orbit around it, or en route to the Moon – it's effectively weightless. If you find that idea difficult, don't worry – Einstein did too. He puzzled over it for years, and when he finally worked it out the result was his famous theory of general relativity.

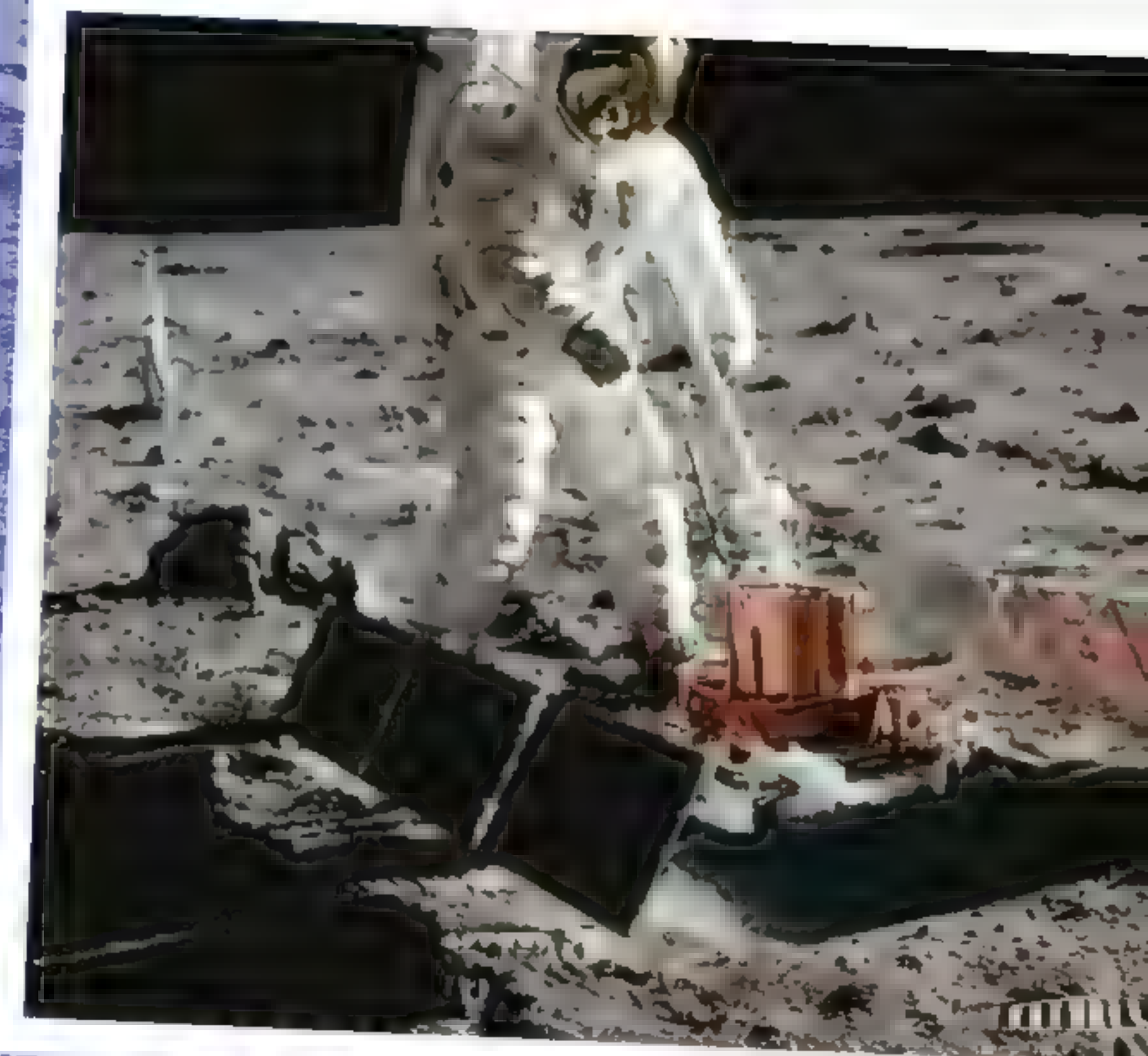
As the astronauts landed on the Moon, they experienced weight again, but only at a sixth of its strength on Earth. Gravitational fields are generated by mass, and the Moon is much less massive.



Astronauts inside the Lunar Module.



The Command Module floating in the Pacific Ocean after splashdown.



The astronauts found time to deploy a few science experiments, such as this seismometer.



Anatomy of the Apollo-Saturn V Moon rocket

It was made of around 3 million separate parts: here are some of the most important ones

Second stage

Using liquid hydrogen fuel, the second stage takes over for another six minutes, getting close to orbital velocity.

Third stage

The third stage – also hydrogen-fuelled – is fired twice: once to enter Earth orbit and then to push onwards to the Moon.

Main engines

A cluster of five rocket engines, each over 5m tall, are needed to lift the near 3,000tn giant off the ground.

First stage

The Saturn V's kerosene-fuelled first stage lifts it to an altitude of 68km in 165 seconds before falling away.

Lunar Module shroud

On ascent, the LM is stowed inside this protective cover, attached to the Saturn V's instrument unit.

Instrument unit

It may look small and insignificant, but this is the brain of the Saturn V – its guidance computer.

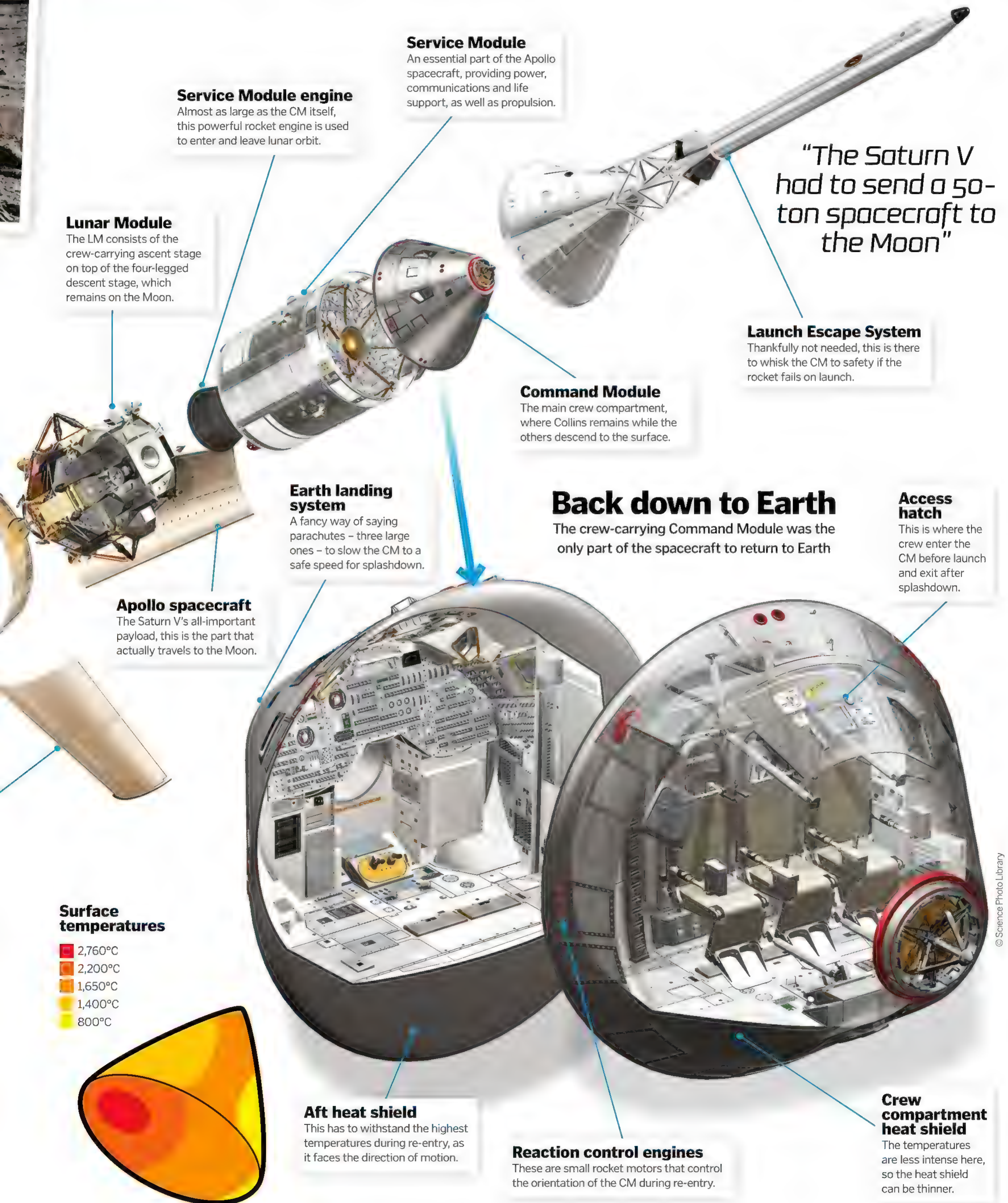
The 'impossible' lunar liftoff

At first sight, it seems odd that the Lunar Module's ascent stage, with just a single small rocket engine, was able to launch two astronauts off the Moon's surface. Didn't it require the enormous Saturn V to get three of them off the Earth? If you look into the physics though, there isn't really any contradiction. The Saturn V had to send a 50-ton spacecraft all the way to the Moon, which calls for a speed of around 11 kilometres per second. In contrast, the LM ascent stage only had to lift itself – less than five tons – while the Moon's weaker gravity meant it could get into lunar orbit with a speed of just 1.6 kilometres per second. So a lot less energy was needed, which is why a smaller rocket did the job.

The ascent stage of the Lunar Module returning from the Moon's surface



DID YOU KNOW? The flag planted by the astronauts had a springy horizontal bar to make it 'wave' in the absence of air



© Science Photo Library



Staying alive with multiple life-support systems

There's no air in space or on the Moon, so the astronauts needed safe and reliable life-support systems. There was one in the CM and one in the LM, as well as a portable life-support system (PLSS) in the backpacks Armstrong and Aldrin wore for their Moonwalk. The Earth's atmosphere is around 80 per cent nitrogen, but humans don't need that to breathe, so

instead the astronauts used pure oxygen at a third of normal pressure.

That was the easy part. They also needed to get rid of the carbon dioxide (CO_2) they exhaled, which can be very dangerous if it builds up. Fortunately there's a powdery chemical called lithium hydroxide (LiOH) that absorbs CO_2 , and the Apollo missions used LiOH canisters to 'scrub' CO_2 from the air.

A rear view of Aldrin on the Moon, showing the bulky PLSS backpack

Emergency oxygen

This is a completely separate system, sufficient for around 30 minutes, in case the main supply fails.

Cooling system

This works by pumping cold water through the astronaut's longjohns (technically a 'liquid cooling and ventilation garment').

Primary oxygen supply

The astronaut's main source of oxygen, enough for four hours on the lunar surface.

Lithium hydroxide canister

Needed to scrub the CO_2 the astronaut breathes out from the air in the suit.

Surviving re-entry into Earth's atmosphere

When the returning Command Module hit the Earth's upper atmosphere, it did so at **enormous speed** – comparable to the speed it left at, around 11 kilometres per second. Although the atmosphere is extremely thin at high altitude, it's compressed by the impact of the spacecraft, and this compression produced a fierce heating effect. The surface of the CM got close to $3,000^\circ\text{C}$, and it would have burnt up like a meteor if it was unprotected. The outer shell – called an ablative heat shield – did burn off, because that's what it was designed to do. The heat shield not only protected the astronauts inside, but by absorbing the energy of re-entry it slowed the craft to the point it could use its parachutes.



It looks like a meteor, but it's the Apollo 8 Command Module re-entering the atmosphere

"Viewers around the world remained glued to their sets"

The effects of too much CO_2

0.04%

Earth-normal concentration

1%

Drowsiness

3%

Strain on heart; hearing difficulties

8%

Loss of consciousness and eventually death

Inside Earth's smaller sibling

The Moon's structure mimics the Earth's, but everything is on a smaller scale

Surface crust

Earth's crust is the part we're familiar with – 6,371km in radius, complete with oceans and surrounding atmosphere.

Molten outer core

The Moon's iron-rich core – hot enough to be liquid in its outer parts – is just 350km in radius.

Sluggish mantle

Like Earth, the Moon has a layered mantle, but it's much less active in geological terms.

Solid inner core

Thanks to seismic measurements by the Apollo missions, we know the Moon's core is solid at the very centre.

Low gravity

With a radius of 1,737.5km, the Moon's gravity is a sixth of Earth's – too weak to retain an atmosphere.

Dense inner core

At 70 per cent of the Moon's radius, and four-times denser, it's a major reason why Earth's gravity is so much stronger.

Huge outer core

Earth's iron core is much larger than the Moon's, the fluid outer part extending more than half way to the surface.

Active mantle

Earth's mantle retains a lot more heat than the Moon's, driving volcanic activity and other geological processes.

Walking on the lunar surface

20 July 1969 20:17:39 UTC

The LM, with Neil Armstrong and Buzz Aldrin on board, touches down in the Sea of Tranquility.

21 July 1969 02:56:15

Armstrong steps onto the lunar surface – "One small step for a man, one giant leap for mankind."

21 July 1969 03:15:16

Aldrin joins Armstrong on the lunar surface – initial glitches have been fixed and TV quality is better now.

21 July 1969 03:41:43

The astronauts erect a specially designed flag, which appears to wave in a nonexistent wind.

21 July 1969 03:48:30

Armstrong and Aldrin break off from more important tasks to take a phone call from US President Richard Nixon.

21 July 1969 04:27:42

Time for some science – deployment of passive seismometer, part of the Early Apollo Scientific Experiments Package.

21 July 1969 05:11:13

Armstrong and Aldrin go back into the LM, having spent just over two hours walking on the Moon.

21 July 1969 17:54:00

The LM's ascent stage blasts off on its return trip to the CM in lunar orbit.

Broadcasting live from the Moon

When Neil Armstrong took his first step onto the Moon, he was watched by a worldwide TV audience estimated at around 650 million – the biggest in history up to that point. Yet getting those TV pictures back to Earth in a matter of seconds was pushing the limits of 1960s technology. The main bottleneck was the Lunar Module's tiny antenna, which was limited to a bandwidth of just 500kHz – less than a tenth of a normal TV signal. The result was a grainy, flickering, black-and-white picture made up of 200 scan lines running at just ten frames per second.

To make matters worse, the first images from the surface, as Armstrong began to descend the ladder, were upside down. That

was quickly put right, but then an anomaly at the ground station in California produced a thick black bar across the screen, marring the audience's view of Armstrong's 'giant leap for mankind'. But it was one of history's greatest moments, and viewers around the world remained glued to their sets for the entire two hours the astronauts were walking on the Moon.

The UK, of course, was no exception, and both the BBC and ITV covered every moment of the lunar mission throughout the night. That might not sound very exceptional today, but this happened in the days before there was 24-hour television, and the Apollo 11 coverage was Britain's first ever all-night broadcast.



Old live TV images from the Moon were historic but poor in quality



Determining the size of the universe

Measuring the enormity of space is a task best left to the professionals – and even they don't know!

The universe is a vast space that is simply incomprehensible to the human mind. The distance between London and New York is considered a large distance by many, but it pales in comparison when you think that it would take 2.5 million years to get to our closest galaxy while travelling at the speed of light.

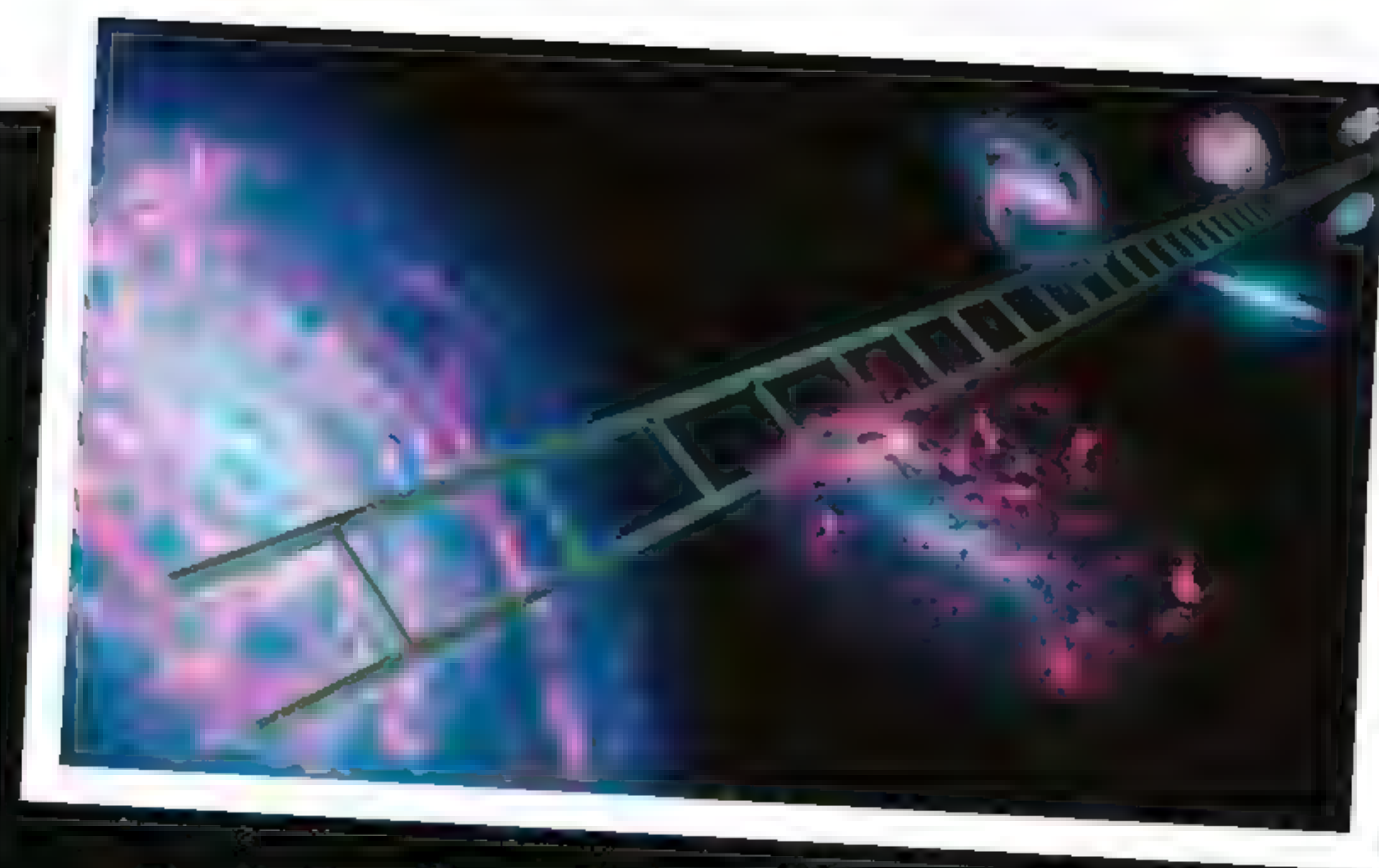
Astronomers have spent decades trying to determine the size and age of the universe, and their closest estimate to the size of the observable universe is 46 billion light years across. This is just the area that astronomers can observe, and in fact they think it could even be double that size. The way they have managed to estimate such a number is through the use of astronomical distance

measuring beacons that are known as 'standard candles'.

The premise is simple. In the same way that you know what the brightness of a candle is while you hold it in front of you, it will gradually appear dimmer the farther it is from you. By measuring the difference in actual and perceived brightness, the distance between you and the candle can be determined. Astronomers use the same method on astronomical objects, and in the case of this research, a group of stars known as Cepheid variables are used. They have been studied for a long time using telescopes such as NASA and ESA's Hubble Space Telescope, and provided help in deducing this mind-boggling figure.

Putting the universe into scale

From the Solar System to the Cosmic Microwave Background, the observable universe is filled with majesty



Standard candles are just one of the methods used in the Cosmic Distance Ladder

How brightness variability can measure distance

Cepheid variables are stars that are extremely useful when it comes to measuring cosmological distances. They are unlike the Sun in that they are usually between four and 20 times more massive than our own star and are much further along in their lifetime. At this later stage, they exhibit a brightness variation due to an inherent instability in the star that causes pulsations and this is used to calculate distances of a few tens of millions of light years.

Astronomers determine the rate of this pulsation, which is the period of variability, of the Cepheid, which has its brightness (or luminosity) inferred by the 'period-luminosity relationship'. The longer their variation the brighter the star is and vice versa. From this relationship, astronomers can use Cepheids as standard candles in their mission to measure the universe.



The timing of a Cepheid pulse is related to its luminosity, allowing a distance to be calculated

The universe beyond our Solar System

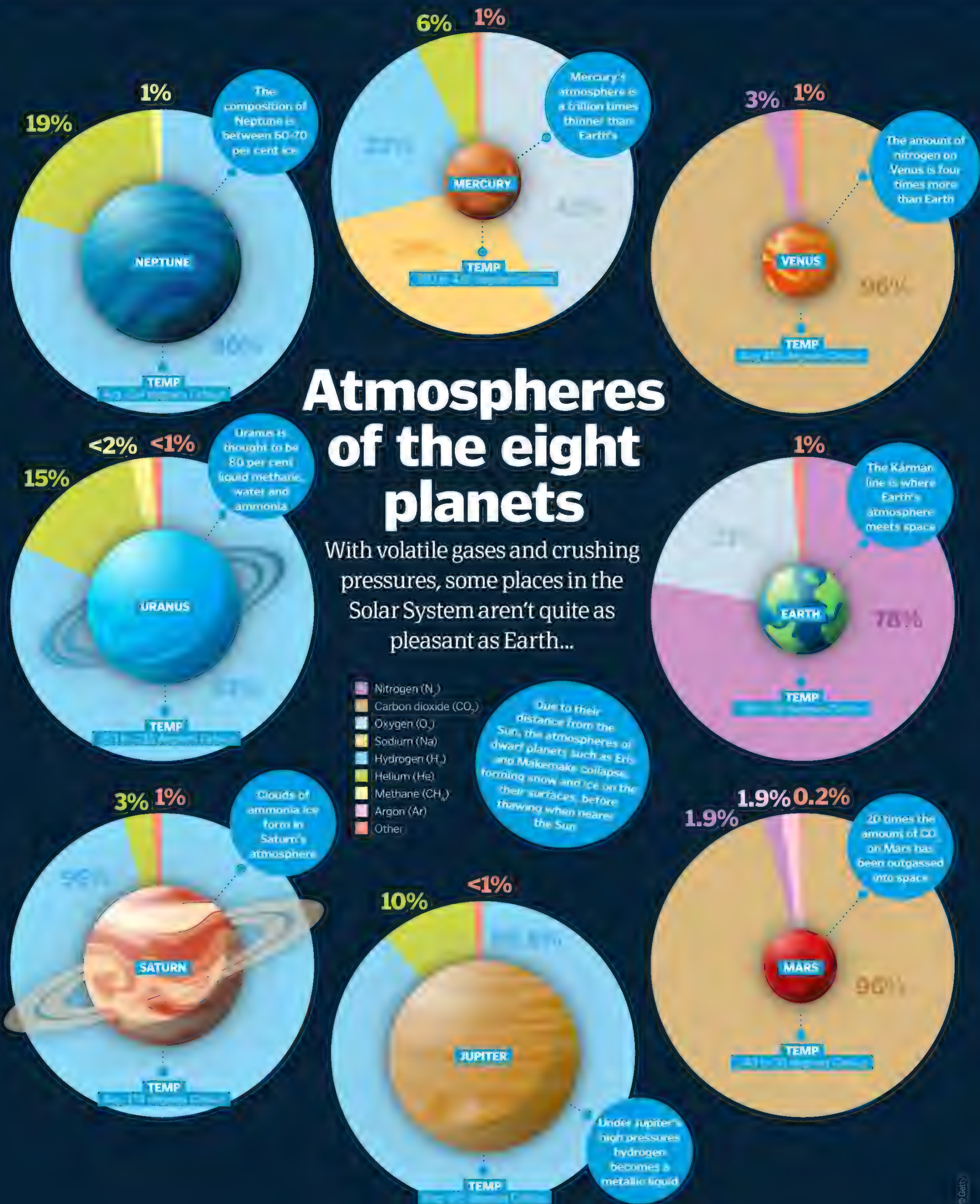
Nicolaus Copernicus may have something to say about this picture, but it's not saying the Solar System is at the centre of the universe. It's an illustrated logarithmic scale concept of the universe we can see. This piece was created by Pablo Carlos Budassi, a musician and artist, and inspired by logarithmic maps created by researchers at Princeton University, New Jersey, US. The picture was created to show how the universe changes logarithmically the further we peer beyond our Solar System, showing stars, galaxies and even the gas created after the Big Bang.

Atmospheres of the eight planets

With volatile gases and crushing pressures, some places in the Solar System aren't quite as pleasant as Earth...

- Nitrogen (N₂)
- Carbon dioxide (CO₂)
- Oxygen (O₂)
- Sodium (Na)
- Hydrogen (H₂)
- Helium (He)
- Methane (CH₄)
- Argon (Ar)
- Other

Due to their distance from the Sun, the atmospheres of dwarf planets such as Eris and Makemake collapse, forming snow and ice on their surfaces, before thawing when nearer the Sun





INSIDE T

P



THE LARGEST

NASA's InSight lander will tell us more about the interior of Mars than ever before

Words by Jonathan O'Callaghan

Over the last five decades we have sent a host of missions to Mars. Some have been orbiters, designed to image the planet from afar. Others were rovers sent to probe the surface and analyse rocks at different locations. But now a new mission will do something we've never done before – it will try and peer inside Mars itself, telling us not only what the planet is made of, but how it and other rocky planets formed.

NASA's InSight mission was launched on 5 May

2018 from the Vandenberg Air Force Base in California on an Atlas V rocket. After a journey of about 485 million kilometres, it touched down on Mars on 26 November 2018. Mars is hard, and many missions have failed, so there was always a chance InSight wouldn't make it. Thankfully it did, and these next few pages will run through what

"InSight will try and peer inside Mars itself"

this pioneering mission will do on Mars for just over one Mars year (two Earth years).

InSight is a stationary lander, like NASA's Phoenix lander on Mars in 2008, which means it won't be roving around the surface. Instead, it will touch down in a location near the equator called Elysium Planitia, where it will stay for the entirety of its mission. This region was picked for a number of reasons, one being that it is relatively smooth, thereby minimising any problems when landing and providing an easy environment in which to conduct science. It also has an abundance of sunlight, meaning InSight's solar panels will

This map depicts InSight's trajectory from Earth to Mars



receive plenty of juice. The landing site is also important for the actual landing itself, giving the spacecraft enough atmosphere to slow itself down.

To touch down on Mars, other spacecraft have relied on airbags or a sky crane system with thrusters, as in the case of the Curiosity rover in 2012, to land on the surface. InSight is a little bit different. First, about seven minutes before it entered the atmosphere it jettisoned the cruise engine that took it to Mars. It then entered the atmosphere at about 21,240 kilometres per hour, with a heat shield taking the brunt of the entry. Temperatures reached approximately 1,500 degrees Celsius as InSight descended.

Roughly three and half minutes after entering the atmosphere InSight deployed its parachute 12 kilometres above the surface, travelling at 1,500 kilometres per hour. The spacecraft descended with its parachute for about three minutes, using its radar to sense the distance to the ground and extending its three legs. Then, 1.2 kilometres above the surface, it used 12 descent engines to slow itself down, bringing it to a relatively gentle touchdown at 8.7 kilometres per hour.

Once on the surface, the real fun began. The lander got to work immediately, unfurling its ten-sided solar panels to create a collection area the size of a ping-pong table. On top of the lander are its various instruments and pieces of equipment, a smorgasbord that a robotic arm with a mechanical hand will be able to grab and place on the surface. Before it did this, though, it used two onboard cameras to image the surrounding area and pick the best place to deploy its instruments.

These instruments are designed to study Mars in a whole new way. Previous missions have focused on the surface, but InSight will be looking underground. Of particular interest is trying to work out what is actually inside Mars and how similar its interior is to Earth. While both planets are rocky, Mars is now a relatively dead and dusty world. Under its surface could be a whole different matter, however, so a seismometer experiment called the Seismic Experiment for Interior Structure (SEIS) will be placed on the surface to try and listen to seismic waves travelling throughout Mars. These are produced by so-called 'marsquakes' in a number of ways, one being

meteorites hitting the surface, another being the planet cooling and contracting, and another being magma rising up from its suspected molten core.

By monitoring these waves and measuring their speed, frequency and size, the seismometer will be able to work out what material is inside Mars. We don't actually

know if the core of Mars is solid or liquid, something this experiment could reveal. We also don't know how thick its next two layers are, the mantle and crust, the former likely rich in silicon and the latter made of

less-dense rocky material. Studying exactly what Mars is made of, and how its structured, could not only tell us about the Red Planet itself but others too.

Our Solar System has four rocky planets, but we're starting to find bucket-loads elsewhere in the galaxy. In our Solar System though, only one - Earth - became the habitable, pleasant world it is today. Understanding the formation and structure of Mars could help tell us why Mars is not the

"Once on the surface, the real fun begins"

SEIS instrument

The Seismic Experiment for Interior Structure (SEIS) will take the 'pulse' of Mars. Shaped like a dome, the instrument will measure the seismic vibrations of the planet caused by meteorite impacts and 'marsquakes'. It'll also measure vibrations caused by Martian weather, and it could even find liquid water underground.

Pendulums

The motion of three pendulums inside the SEIS instrument will be measured electronically to detect vibrations.

Shield

A wind and thermal shield will be placed over SEIS so its measurements aren't interrupted.

Ground

The SEIS instrument will be placed onto the surface by the arm onboard InSight.

Solar arrays

Two ten-sided solar arrays, each 2.15m across, will deploy on the surface to provide power to the lander.

InSight's equipment

How this lander will study the surface of Mars like never before

A large parachute helped InSight land on the Martian surface

DID YOU KNOW? InSight is the first lander to ever use a robotic arm to grasp instruments on the surface of another planet

Instrument Deployment Camera

The Instrument Deployment Camera (IDC) will take colour images to pick locations to deploy the instruments.

Instrument Deployment Arm

This 2.4m-long arm will remove instruments from the lander and place them on the ground.

Grapple

This 'hand' at the end of the arm has five mechanical fingers that will grab instruments from the lander.

Ultrahigh Frequency (UHF) antenna

The lander's UHF antenna will send data to orbiting Mars spacecraft to be relayed to Earth.

RISE antenna

The Rotation and Interior Structure Experiment (RISE) will measure the wobble of the planet, specifically the north pole, where InSight will be landing. This will help us work out if the core is liquid and what it's made of, telling us how similar Mars is to Earth inside.

Instrument Context Camera

The Instrument Context Camera (ICC) has a fisheye lens that will take wide images of the lander and its surroundings.

HP³ instrument

The Heat Flow and Physical Properties Probe (HP³) will measure the temperature of Mars. It will do this by hammering a sensor as far as 5m underground. This will measure how much heat is coming from the interior of Mars, telling us what's going on inside the Red Planet.

The launch

InSight was launched from Vandenberg Air Force Base on the central coast of California on 5 May 2018. That choice of launch site was somewhat unusual, as missions to other planets usually lift off from NASA's Kennedy Space Center in Florida. From the latter, rockets can launch east over the sea, getting an additional boost to their momentum from Earth's rotation. However, InSight was launched on the powerful Atlas V-401 rocket, which was strong enough that it could launch the spacecraft south from Vandenberg over water.

The launch took place in rather foggy conditions on 5 May 2018.

THE UNIVERSITY OF CHICAGO

same, although we do think it once had water on its surface just like Earth. Learning how Mars formed differently to Earth will be crucial in understanding the broader picture of what ingredients a rocky planet needs to become habitable.

Helping in this endeavour will be another instrument deployed by InSight called the Heat Flow and Physical Properties Package (HP³), developed by the German Aerospace Center (DLR). This is essentially a probe that will be hammered into the surface of Mars up to a depth of five metres, deeper than any instrument on Mars before. A motor will create tension in a spring, which will drive a hammer down a cylindrical shaft into a spike at the bottom called the 'mole', requiring between 5,000 and 20,000 hits over 30 to 40 days depending on how compact the soil is. This will gradually burrow into the ground, and once it reaches its maximum depth, 14 sensors up the tether will begin to measure the temperature at different depths.

Why? Well, the goal of HP³ is to work out how much heat is flowing out of the interior of Mars and the rate it is doing so as it travels up the sensors. Heat flow is deemed to be a

planet's 'vital sign', with heat being crucial to shaping the geology of a planet, from its canyons to its mountains. It can also play a role in delivering water to the surface, and we think there might be some water hiding under the surface of Mars. What's more, if the energy of Mars' core is diminishing – which it might be, as the planet mysteriously lost its magnetic field billions of years ago, one likely powered by an active core – then this instrument could tell us how long Mars has left before it truly dies.

The last main science goal aboard InSight

is the Rotation and Interior Structure Experiment (RISE). Unlike the other two experiments, however, this does not have its own

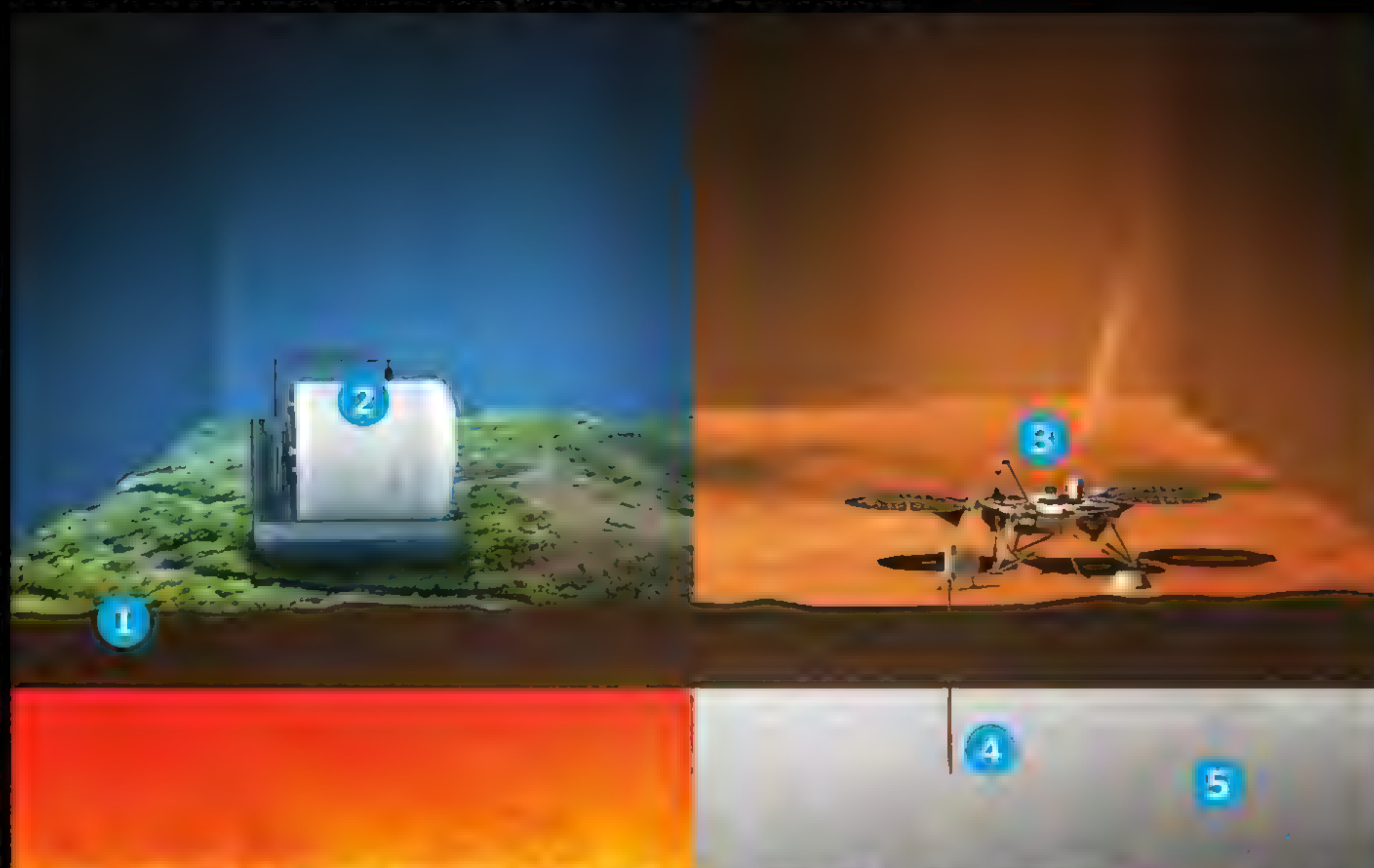
dedicated equipment. Instead, it will be using the direct radio connection InSight has with Earth to measure how much Mars is wobbling as it rotates. Amazingly, InSight will use its antennae to measure its location in space to a precision of less than ten centimetres. This will tell us how much the rotation axis of Mars is swaying.

This is important because it will tell us how big the core of Mars is. Previous findings have suggested the core is extremely dense and

"InSight is a groundbreaking mission"

Seismic activity

How we can measure seismic activity on Mars compared to Earth



1 Rocks

When rocks move or break apart we can measure the seismic waves they produce as they bounce around the planet.

2 Seismometer

A seismometer is specifically designed to measure the size, frequency and speed of seismic waves, also called quakes.

3 Location

On Earth we take measurements from multiple locations, but InSight will have to do it from just one.

4 Number

InSight is expected to detect up to several hundred seismic waves, as well as quakes produced by meteorite impacts.

5 Material

Detecting the characteristics of the wave can tell us what material it has passed through – a glimpse at Mars' interior.



InSight could tell us more about rocky planets in our Solar System and beyond

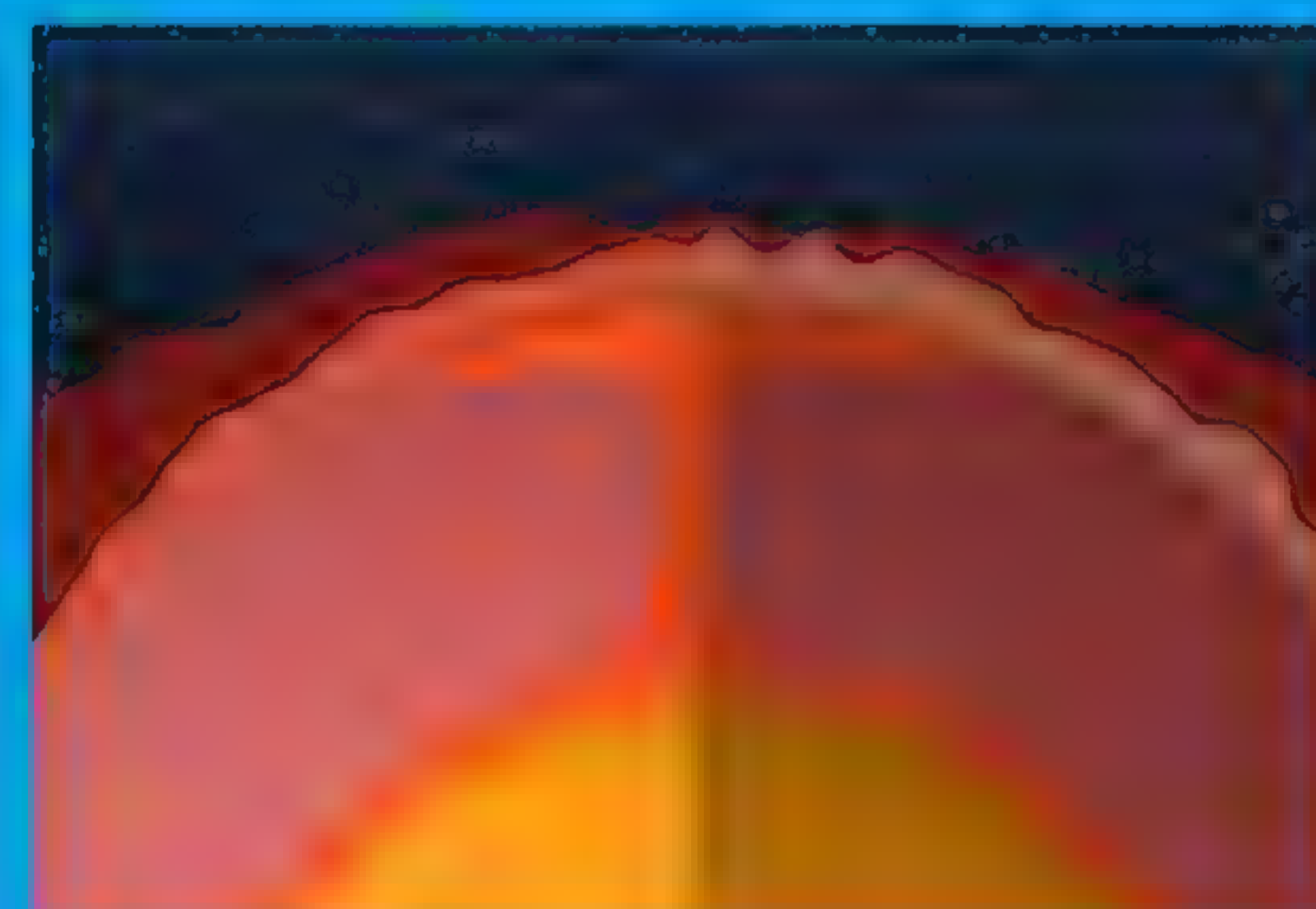
Marsquakes

Mars doesn't have plate tectonics like Earth, so how does it have quakes?



Contraction

As Mars cools, the crust contracts, creating stresses that can lead to quakes.



Magma

Convection in the mantle can create stresses that lead to quakes.



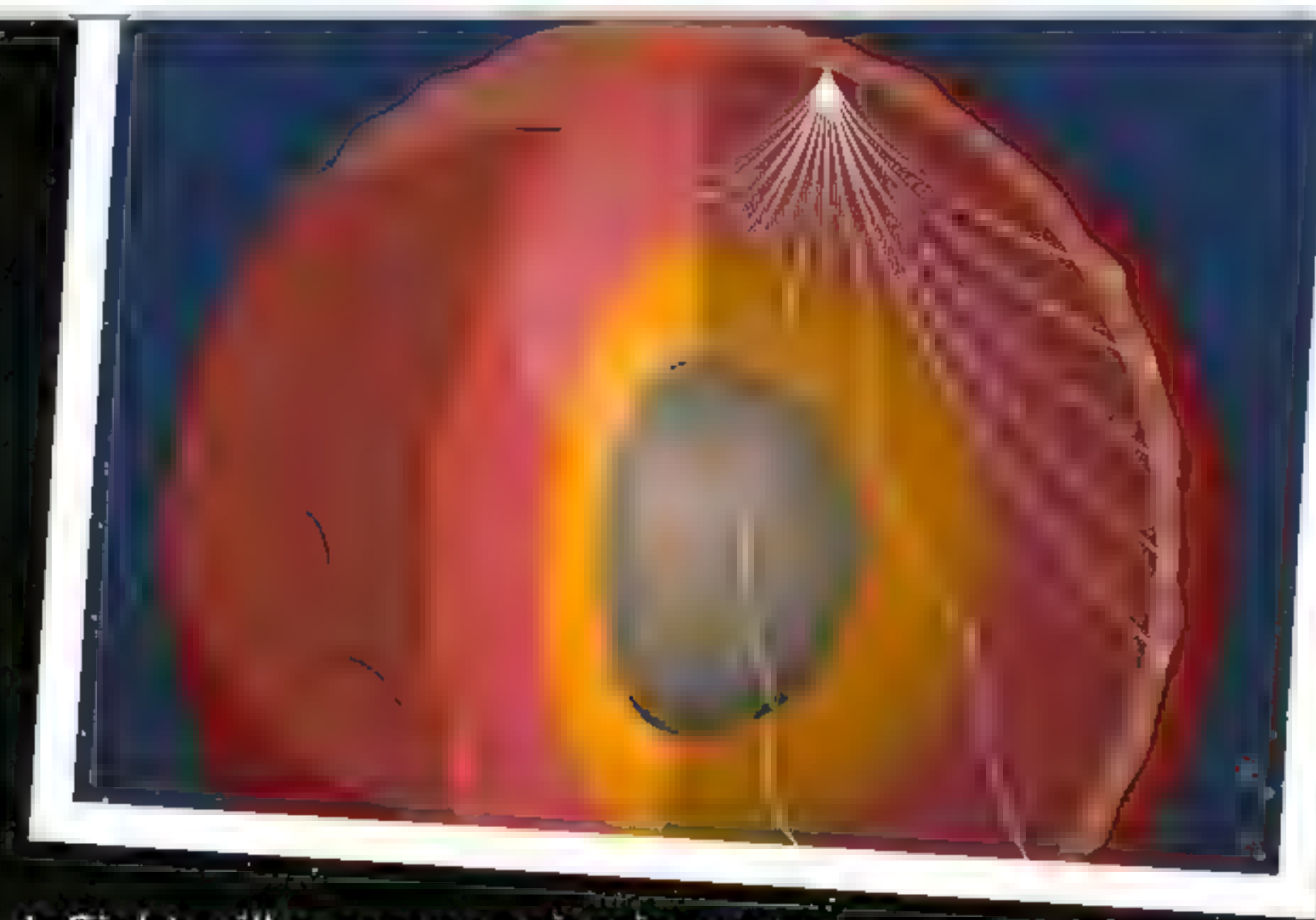
Impacts

Impacts from meteorites can create seismic waves that travel through the planet.

possibly partly molten, but to find out its exact size we need to monitor it for a long time. Rovers and orbiters aren't very good at doing this as they keep moving around, but InSight will be staying in one location. It's hoped this could tell us a huge amount about the core of Mars and, in turn, tell us more about the innards of rocky planets in general.

There's little doubt that InSight is, in every sense of the word, a groundbreaking mission.

It will literally hammer into the ground, while simultaneously listening to the pulse of the planet and the wobble in its spin. The primary mission of the lander is expected to end on 24 November 2020, and by then we might have a whole different outlook on just how special Earth is in the universe compared to other rocky planets. Perhaps Mars was once more like us than we thought – or perhaps our planet really is one of a kind.



InSight will measure seismic waves travelling through the surface of Mars

Rocky planet formation

How we think terrestrial planets form and what InSight could add

Pebble

Our leading theory is the 'pebble method', that small rocks gradually join together (accrete) over time under gravity.

Birth

As the protoplanet grows in size it scoops up more and more pebbles from the surrounding space.

Melt

Elements inside the planet start to heat up and melt as the planet begins to form.

Heat

The pressure at its core increases as the planet grows, as does its temperature.

Core

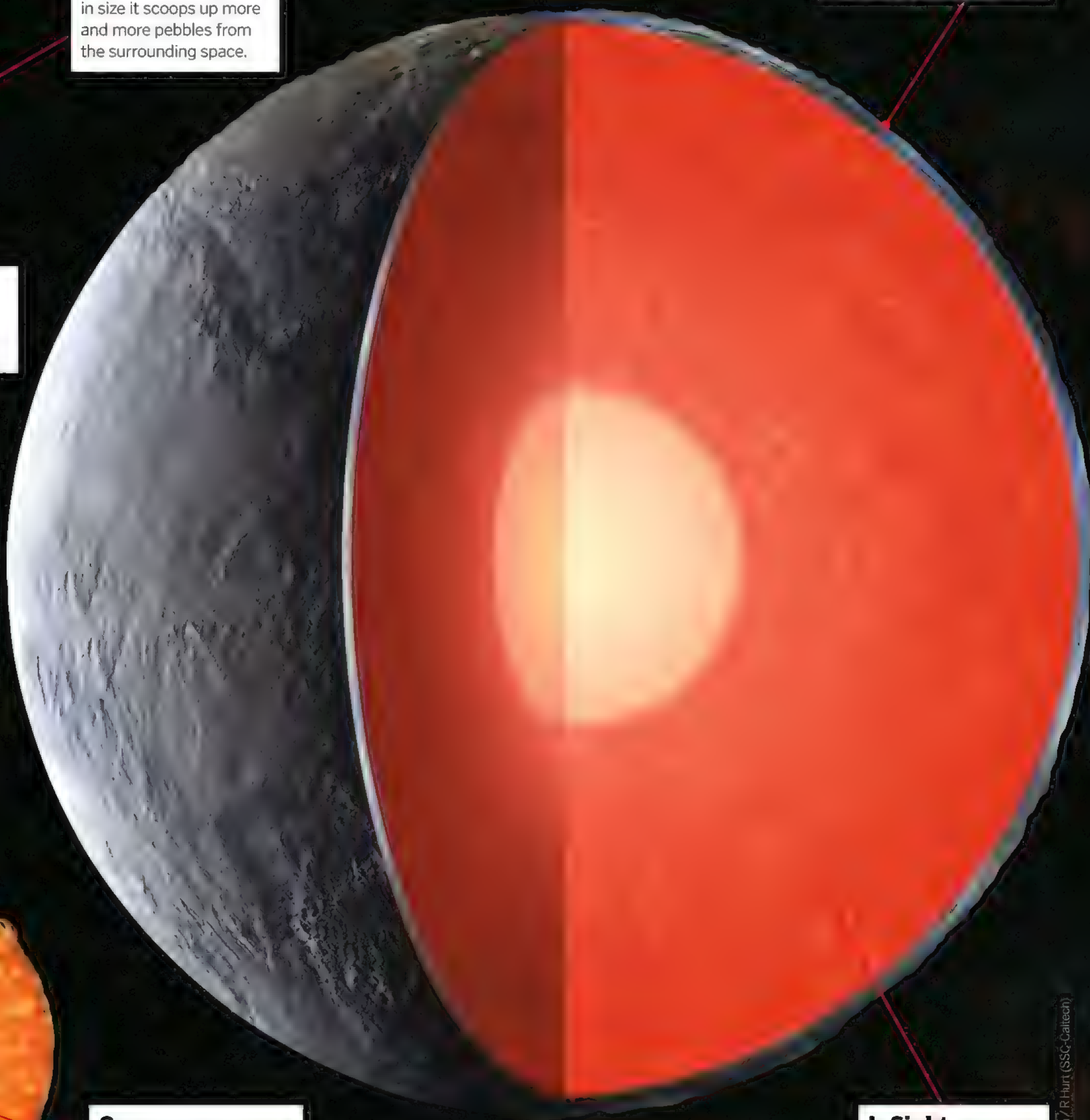
The lighter elements float towards the surface of the planet, while the heavier elements sink to the core.

Layers

The planet is now separated into layers, with a hard crust above the mantle and the core in the middle.

InSight

By studying Mars' innards, InSight will try to see signs of how this planet took shape.



What happens when galaxies collide?

What a cosmic pile-up will mean for the Milky Way

Astronomers already knew that our galaxy, in which our Sun is one of a 100 billion or more stars, is on a collision course with its slightly bigger neighbour, Andromeda. Now, thanks to detailed measurements of stellar motions by the Gaia space telescope, we've got a clearer idea of when the crash is due to occur: in around 4.5 billion years. That's roughly the age of the Earth, so there's no immediate cause for alarm.

Even when the collision happens, it will be a sedate affair hardly noticeable to any creatures still around in that far distant future – apart from giving them some spectacular night-sky views. In fact 'collision' is a misnomer. A galaxy is mostly empty

space, so it's closer to the truth to say they 'pass through' each other. There's little chance of an individual star actually crashing into another star.

We know what happens during a galactic collision as telescopes can see them in action elsewhere in the universe. The most striking effect is on the shape of a galaxy. What started out as a neat disc or elegant spiral can be contorted beyond recognition by tidal forces. If the collision speed is slow, the two galaxies may not have enough energy to separate again, resulting in an eventual merger into a single giant galaxy. Astronomers believe that will happen with the Milky Way and Andromeda – and they've coined the name 'Milkomeda' for the future combined galaxy.

Galactic tides

As distance between galaxies gets smaller, they begin to distort each other via tidal stresses. These arise because the pull of gravity on one side of the galaxy is stronger than on the other, analogous to the way the Moon pulls more strongly on one side of the Earth. Just as the Moon raises tides by distorting the shape of the ocean, so one galaxy can alter the shape of another – on a vaster scale. Stars inside the galaxy can be flung onto completely different orbits, sometimes forming long 'tidal tails'. According to one estimate, the Sun has a small chance of ending up in such a tail, but if so, it's likely to take its retinue of planets with it, so the Solar System would survive unscathed.



The Gaia space telescope's mission is to create a map of the Milky Way

Eight billion years to Milkomeda

How the night sky might change as the Milky Way and Andromeda collide

Present day

The Andromeda galaxy is a faint smudge, about the size of the Moon, to the left of the Milky Way.

After 2.5 billion years

As Andromeda approaches, it becomes a much larger and brighter feature in the sky.

After 4.3 billion years

Andromeda now spans half the sky, rivalling the Milky Way in magnificence.

After 4.4 billion years

As the galaxies begin to overlap, the increased gas density generates star formation.

After 4.5 billion years

The galaxies become an amorphous mass, at the height of the collision, star formation continues.

After 4.6 billion years

As the galaxies move apart, both will show clear signs of tidal distortion, with visible tails.

After 6 billion years

After the frenzy of star formation, little gas is left as the galaxies meet for the last time.

After 8 billion years

Two become one. The the core of a newly merged galaxy – Milkomeda.



Redshift and blueshift

How this weird phenomenon can help us study the distant universe

If you've ever heard a police car drive by with its sirens blaring, you'll be able to understand redshift and blueshift. As the car went past you probably noticed that it sounded higher pitched as it approached you and lower pitched as it drove away. This is known as the Doppler effect, and it's caused by sound waves being pushed closer or further away from each other.

The same thing happens with light. It turns out that as a light source moves towards or away from us on a large scale, the light also gets shifted – but in this case its wavelength

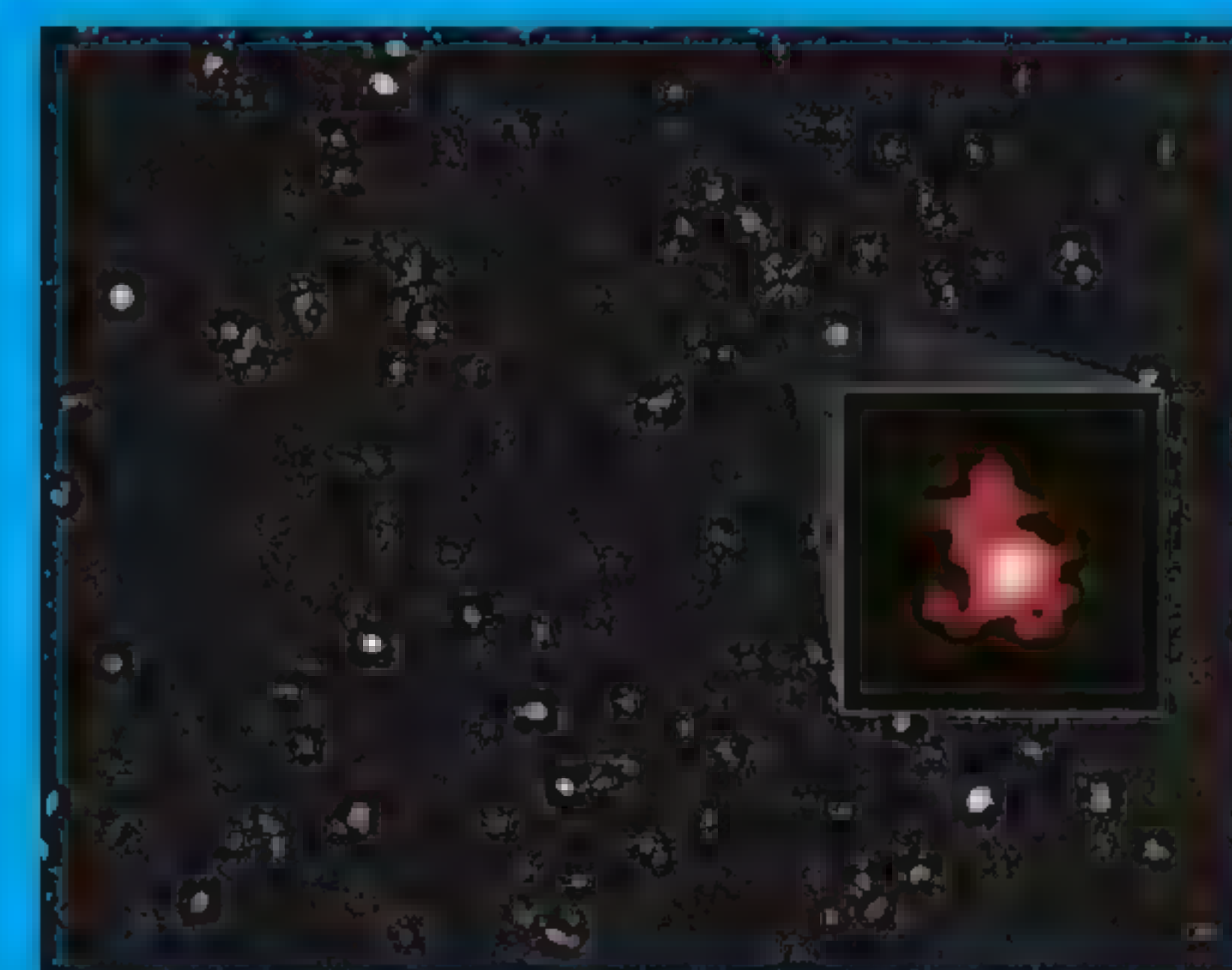
on the electromagnetic spectrum gets shorter or longer. Wavelength is basically an energy pattern in light that determines what colour it is. Longer wavelengths correspond to red, while shorter wavelengths correspond to blue or violet.

When we observe a galaxy in the universe, we find that its light is generally either redshifted or blueshifted. The former is more common, as the universe is expanding and everything is moving away from everything else. The more distant a galaxy is – and thus the faster it is moving away from us – the higher its redshift is.

A few galaxies, like the Andromeda Galaxy, are moving towards us however and are on a collision course with our Milky Way. Andromeda's light is blueshifted. Galaxies that are spinning can also exhibit a slight blue or redshift, as one side of the galaxy moves towards us while the other moves away from us.

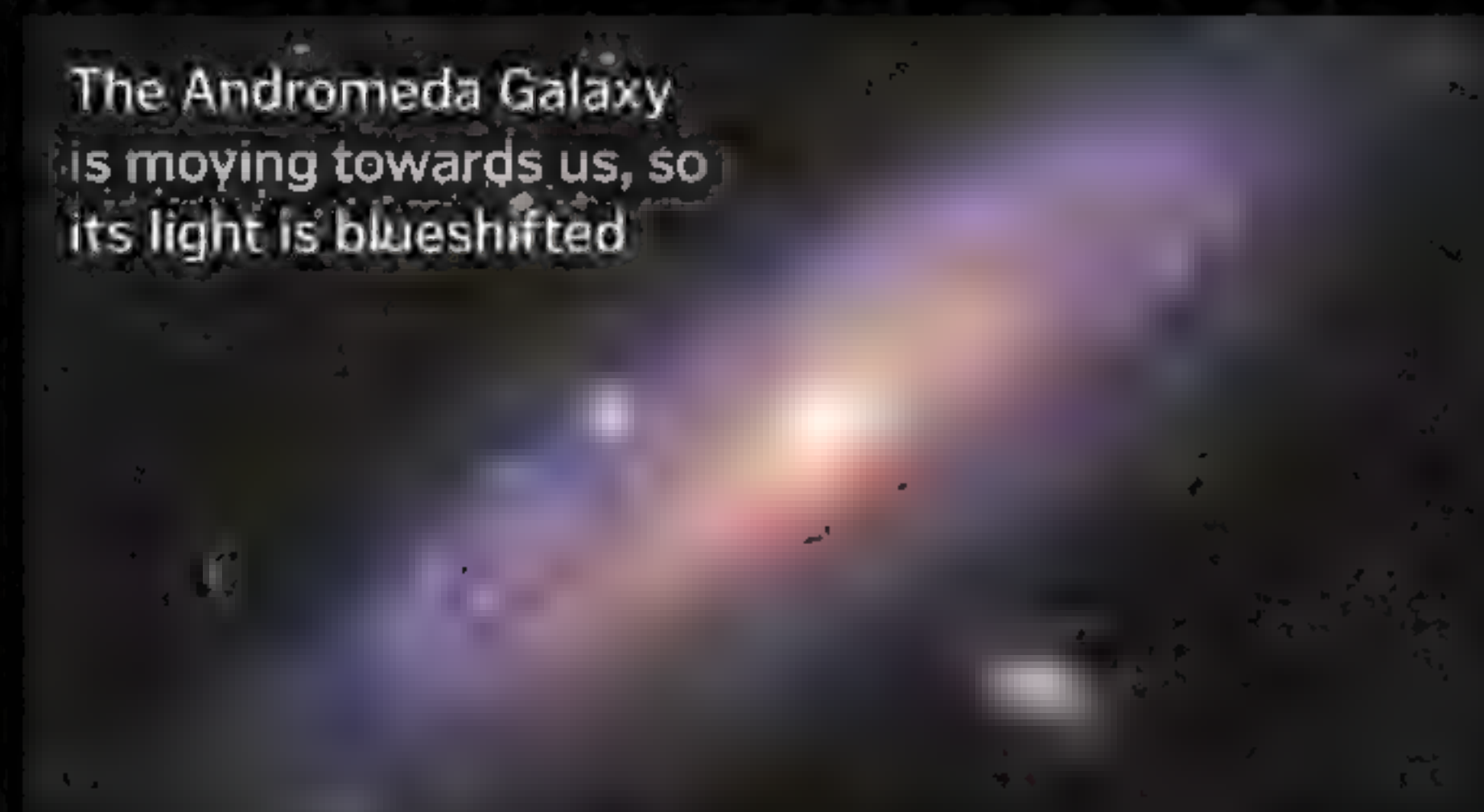
The most distant galaxy

We can use redshift to measure how far away the most distant galaxies we can see are. As a galaxy increases in speed and thus gets further away, its redshift increases. Currently, the most distant galaxy we've seen in the universe is GN-z11, which has a redshift value of 11.09. This corresponds to a distance of 13.4 billion lightyears in terms of how far the light has travelled to reach us across the universe. This also means we are looking far back in time, to just 400 million years after the Big Bang. Astronomers are now hoping to look even further back towards the Big Bang itself to find some of the first galaxies that formed in the universe.



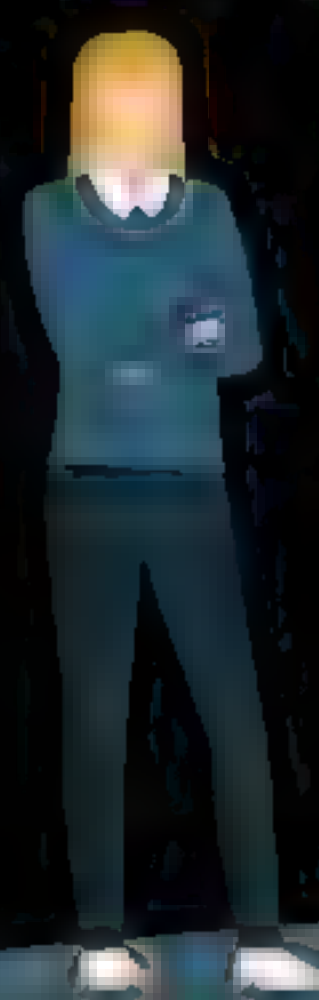
The bright infant galaxy GN-z11 is located in the constellation of Leo.

The Andromeda Galaxy is moving towards us, so its light is blueshifted



Pushed and pulled

How a moving object can change both its sound and light



Low pitch

The sound waves that are stretched have a lower pitch, as the waves are further apart.

Moving car

As a police car drives past you with its siren on the sound waves are stretched and compressed.



High pitch

The sound waves that are compressed are pushed together and therefore have a higher pitch.

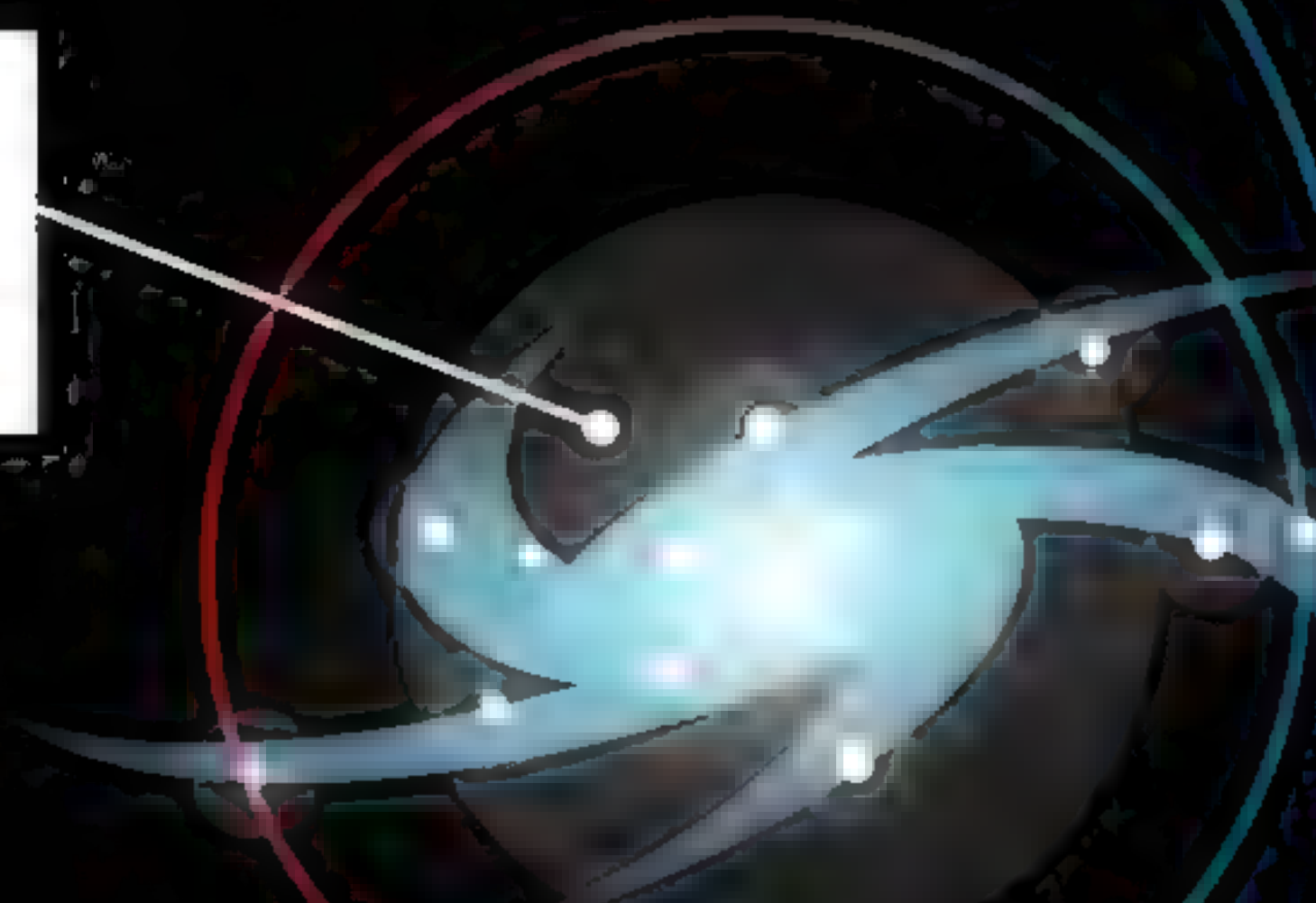


Redshift

As the galaxy moves away, its light is more stretched and moves to the red end of the spectrum.

Moving galaxy

A similar effect happens with a galaxy as it moves towards or away from us.



Blueshift

As a galaxy moves towards us its light is compressed and becomes bluer.





IMPACT EARTH!

**How massive meteorites have shaped our planet
for better and for worse**

Words by Jonathan O'Callaghan

Earth sure hasn't had it easy. Throughout its life our planet has been repeatedly hit, pummelled and even shattered by incoming space rocks, at times wiping out vast swathes of life and significantly changing our planet's habitability. But these mega impacts haven't just caused mass extinctions; they've also been responsible for allowing life to thrive here in the first place, and our very own Moon may owe its existence to a colossal impact long ago.

Our Solar System is full of asteroids and comets, pieces of debris left over from the Sun's infancy that failed to form into planets. Some of these orbit close to Earth and are known as near-Earth asteroids, the ones that make the closest passes to our world. The majority of asteroids in our Solar System can be found in the asteroid belt between Mars

and Jupiter, home to millions of asteroids, with the largest being Vesta, which has a mean diameter of 530 kilometres. Farther out in the Solar System you'll find Trojan asteroids, which share orbits with the larger planets, and in the outer Solar System, the Kuiper Belt and beyond you'll find pieces of icy rock. Occasionally, a comet from out here makes its way towards Earth.

If one of these rocks gets set on a collision course with Earth the consequences for us can be dire. Most debris from the Solar System simply burns up in our atmosphere and causes us few problems, becoming what's called a meteor. If they're big enough, however, they can make it to the surface in the form of a meteorite. And the bigger a meteorite is, the bigger an impact it'll have on our planet. We measure the impact an asteroid could have on

**"OUR PLANET HAS BEEN REPEATEDLY
HIT BY SPACE ROCKS"**



Professor Kurt Kjær collecting a sample from the newly discovered Hiawatha Crater in Greenland

our planet using the Torino Scale, which ranges from 0 to 10. An object at the lower end has less chance of an impact and poses few dangers to life on Earth. At the upper end an impact is a near certainty, and the prospects for life surviving are slim. Fortunately, we know of no objects above a zero on the scale at the moment.

In the past, of course, we have indeed been hit by such objects, although long before modern humans were around. Most of these impacts leave noticeable scars on our surface in the form of craters. For impacts that happened long ago, these craters can be hidden beneath new land, requiring us to dig underground or search underwater for remnants of them. For the most part, with our detailed satellite imagery of the planet, we've done a pretty good job of finding most of the noticeable craters.

In November 2018, scientists announced the discovery of a huge new crater hiding beneath the Greenland ice sheet. Called the Hiawatha Crater, this mammoth depression measures 31 kilometres across, making it one of the 25 largest impact craters on Earth. This is not only the biggest new crater discovered in recent history but the first crater we have ever found under an ice sheet. Its existence suggests there could be many more discoveries to come.

This crater was found by flying over Greenland and using ice-penetrating radar to peer below the ice. Scientists use this technique to monitor the effects of climate change and see how much

ice is melting. They were surprised to discover something else too. As the ice continues to melt and the landscape changes it is revealing previously undiscovered features – including a huge impact crater. Once the team had spotted what looked like a hidden crater they began to optimise and enhance the available data to see if they could get a better picture of it. This included taking further radar images in May 2016 in an attempt to create a clearer picture of what was under the ice. These results showed their initial assumption had been correct – there was a larger crater with a rim around it.

To find out what might have caused the crater, Professor Kurt Kjær from the Natural History Museum of Denmark – who led the project – travelled to the site in July 2016 to collect samples. The crater is buried several kilometres

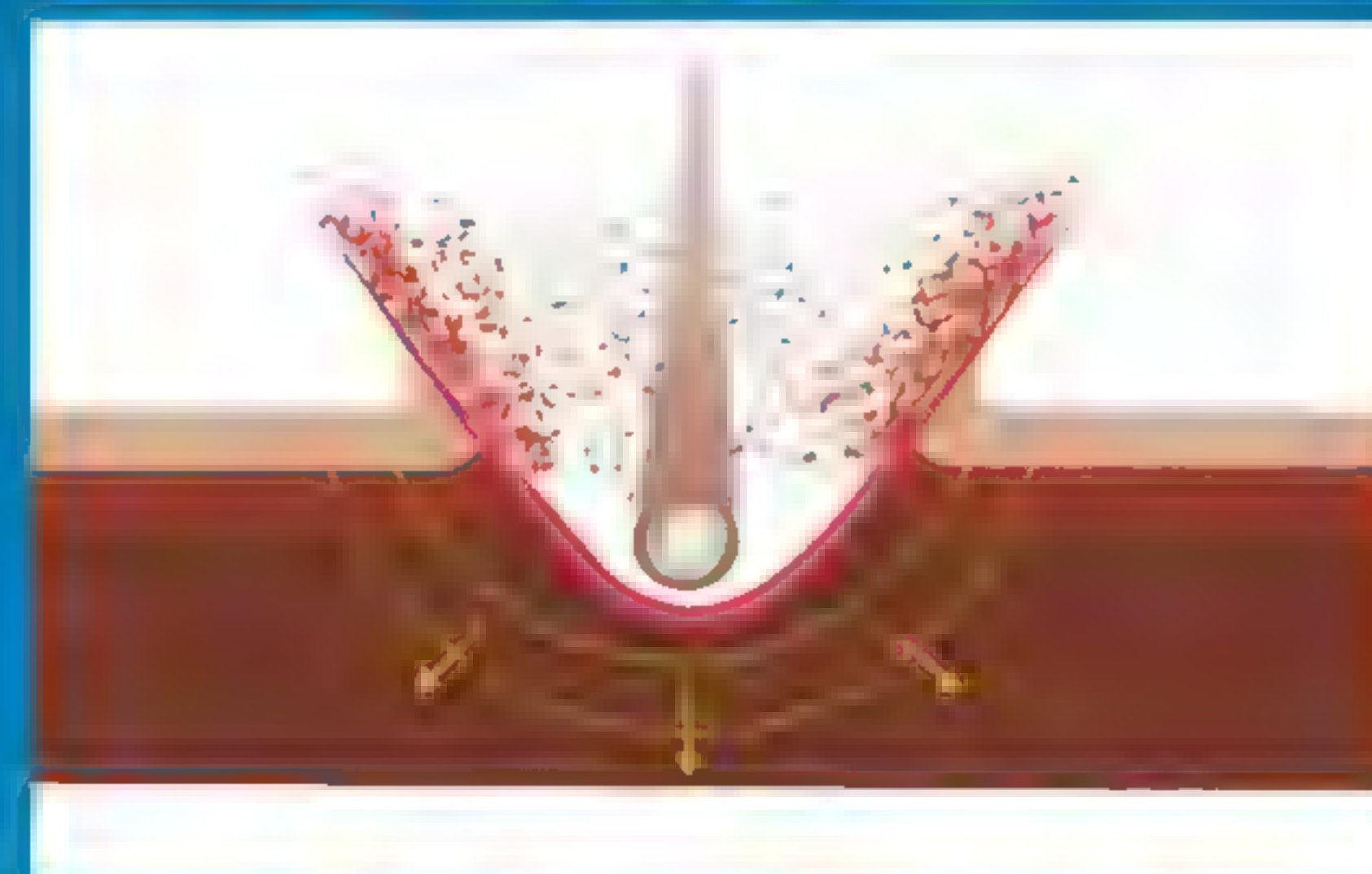
below the ice, so it is not possible to directly sample it, but Professor Kjær found that part of the glacier that housed the crater was melting, meaning meltwater containing minerals from the crater was seeping out. He collected samples of this water and found the smoking gun that pointed to an asteroid impact. The meltwater contained quartz grains that had been shocked, most likely by an impact.

It is thought that this crater was caused by an iron asteroid measuring about 1.5 kilometres across striking the Earth's surface at a velocity of 20 kilometres per second. This would give it an impact force large enough to have caused this

"HOW DID ONE SO BIG MANAGE TO AVOID OUR DETECTION?"

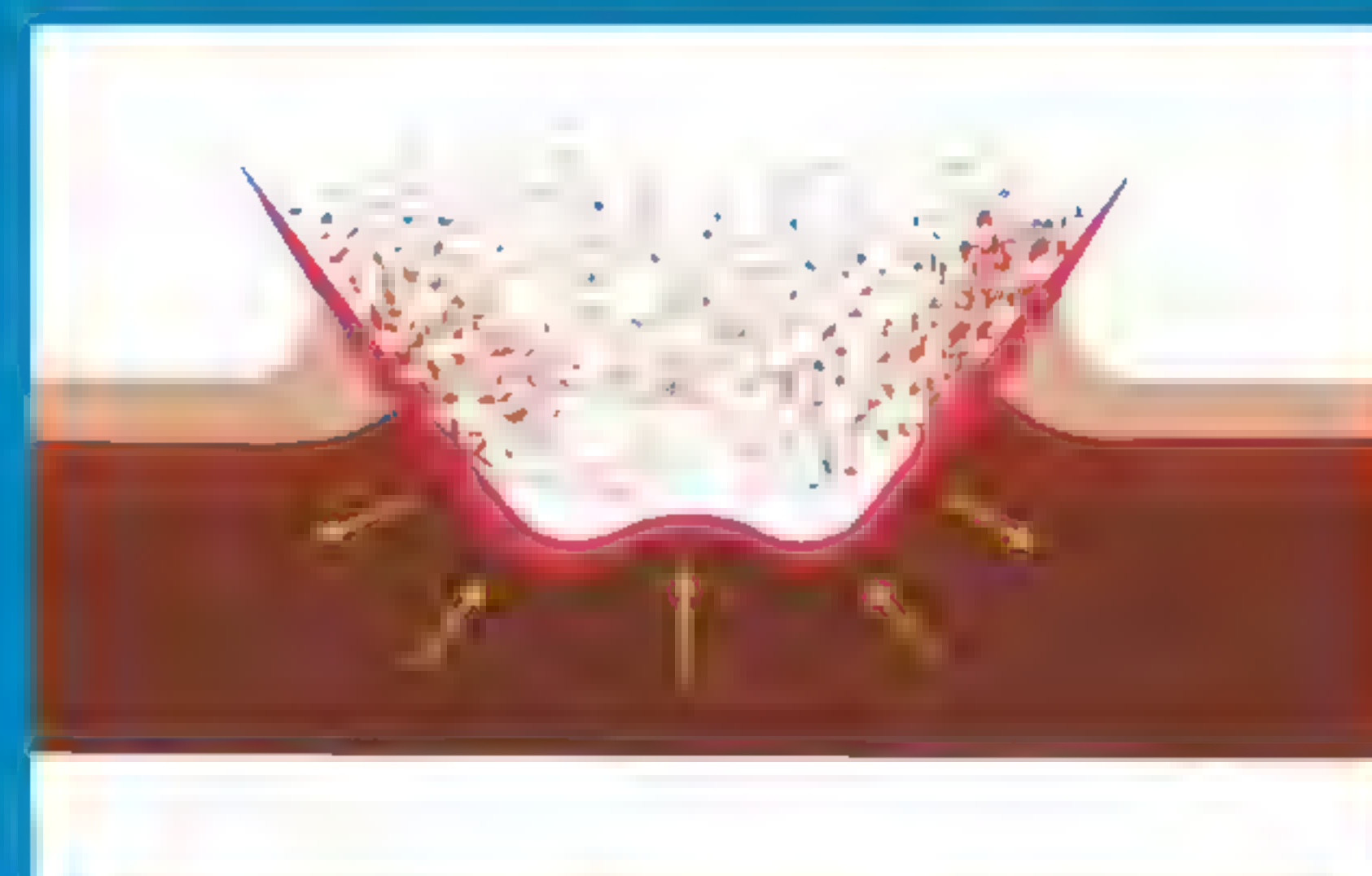
Making a big impression

How the classic crater formation is created by large impacts



Smashing the surface

Complex craters are formed by large impacts, tending to be wider across but shallower in depth (compared to their diameter) than simple craters formed by smaller impacts



Crater walls

The force of the impact causes the walls to collapse downwards, adding debris to the interior of the crater and decreasing its depth



Central peak

Complex craters also have a hump in the middle, where material has rebounded from the impact to form a shallower mound that protrudes upwards



Final diameter

On Earth, complex craters tend to be more than four kilometres in diameter. On different planets, gravity has a significant effect on the type of crater formed



huge crater beneath the ice sheet. The next largest impact crater is the Tookoonooka crater in Australia, which measures 66 kilometres across. But both pale in comparison to the biggest impact crater found on Earth to date, the Vredefort Crater in South Africa, which has a whopping 300-kilometre diameter.

Most of these larger craters were discovered long ago, so how did one so big manage to avoid our detection for so long? The answer mostly lies in our ability to map below the surface. While we have satellite imagery of pretty much the whole planet, peering beneath the surface is a bit more difficult. But with more and more radar-equipped planes flying over the ice sheets, we're now able to more easily look below this ice to monitor climate change. In so doing we're also able to make fascinating discoveries like this. There may well be more such discoveries awaiting us under the ice.



The Hiawatha Crater is not a closed case just yet though. One of the biggest unanswered questions about this impact is when it took place. The team currently think it occurred anywhere from between 12,000 to 3 million years ago, making it our most recent impact by far – the last major

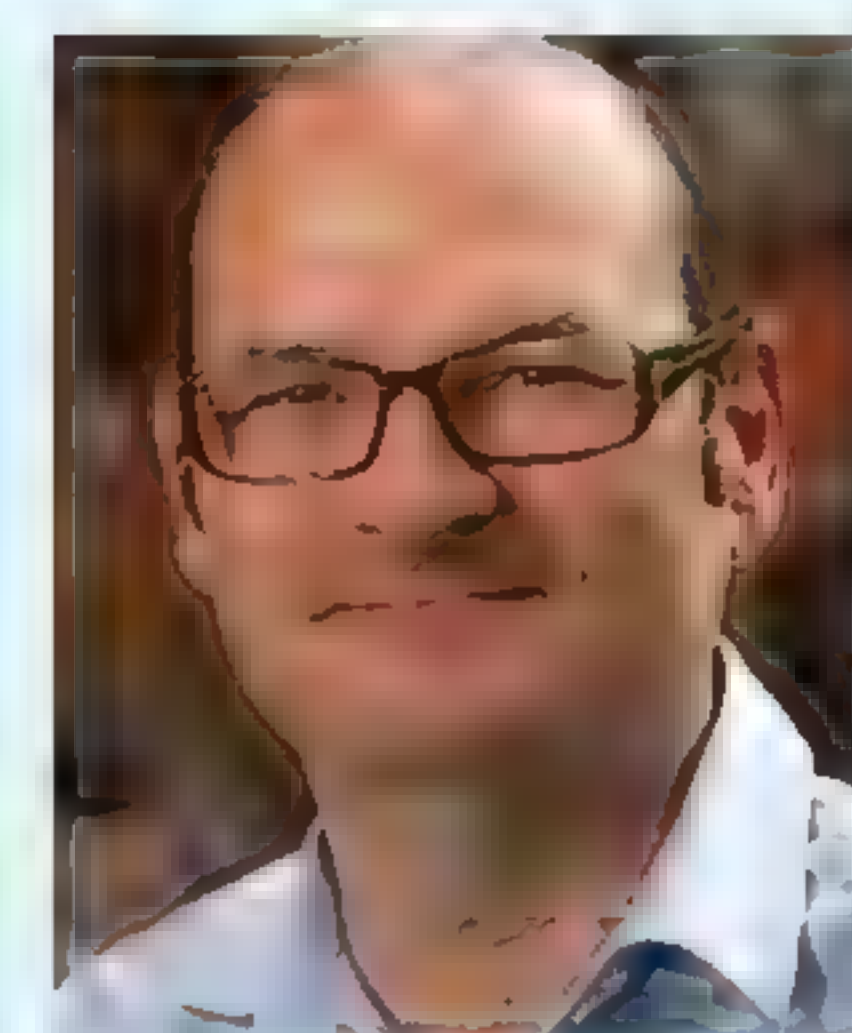
meteorite event before this occurred about 40 million years ago. We know that large impacts like these can have a profound effect on life on our planet, so is it possible the Hiawatha Crater heralds an extinction event?

Scientists have previously struggled to explain the sudden mass extinction of many species that began about 12,900 years ago, called the Younger Dryas. This led to the death of many large animals known as megafauna, while an early human society known as the Clovis people disappeared completely from the archaeological record. Some have suggested a cooling effect on the planet took place, but the reasons aren't

Q&A

Professor Kurt Kjær, Natural History Museum of Denmark

The lead author of the paper published in *Science Advances* talks about the discovery of the Hiawatha Crater



Why was this discovery so exciting?

How often do you find a new, well-preserved impact crater on Earth that is so obvious when you see it? I think it's super exciting because we have thousands of satellites orbiting Earth, we have planes flying everywhere, we record everything that happens on Earth's surface. To discover a thing like this, despite all of these things, in this age where we can see everything from a satellite, it really is a true discovery. You don't have the opportunity as scientists to do that very often.

Why had we not seen this crater before?

Our knowledge of the topography beneath the Greenland ice sheet is getting better and better all the time. Operation IceBridge from NASA has done a great job of doing this, because they map the ice sheets themselves and also map the base of the ice sheets with ice-penetrating radar. A new hidden landscape has started to emerge.

Do we have an idea of when it happened?

When it came out, a lot of people threw themselves on the Younger Dryas hypothesis. We do not do that in the paper. We say we cannot confirm if that is the case, but we cannot reject that hypothesis either. So it might be young – 11,700 years old – very young. And there's some indication [that's the case] due to how it's shaped, how well preserved it is.

Asteroids, meteors, meteorites and comets

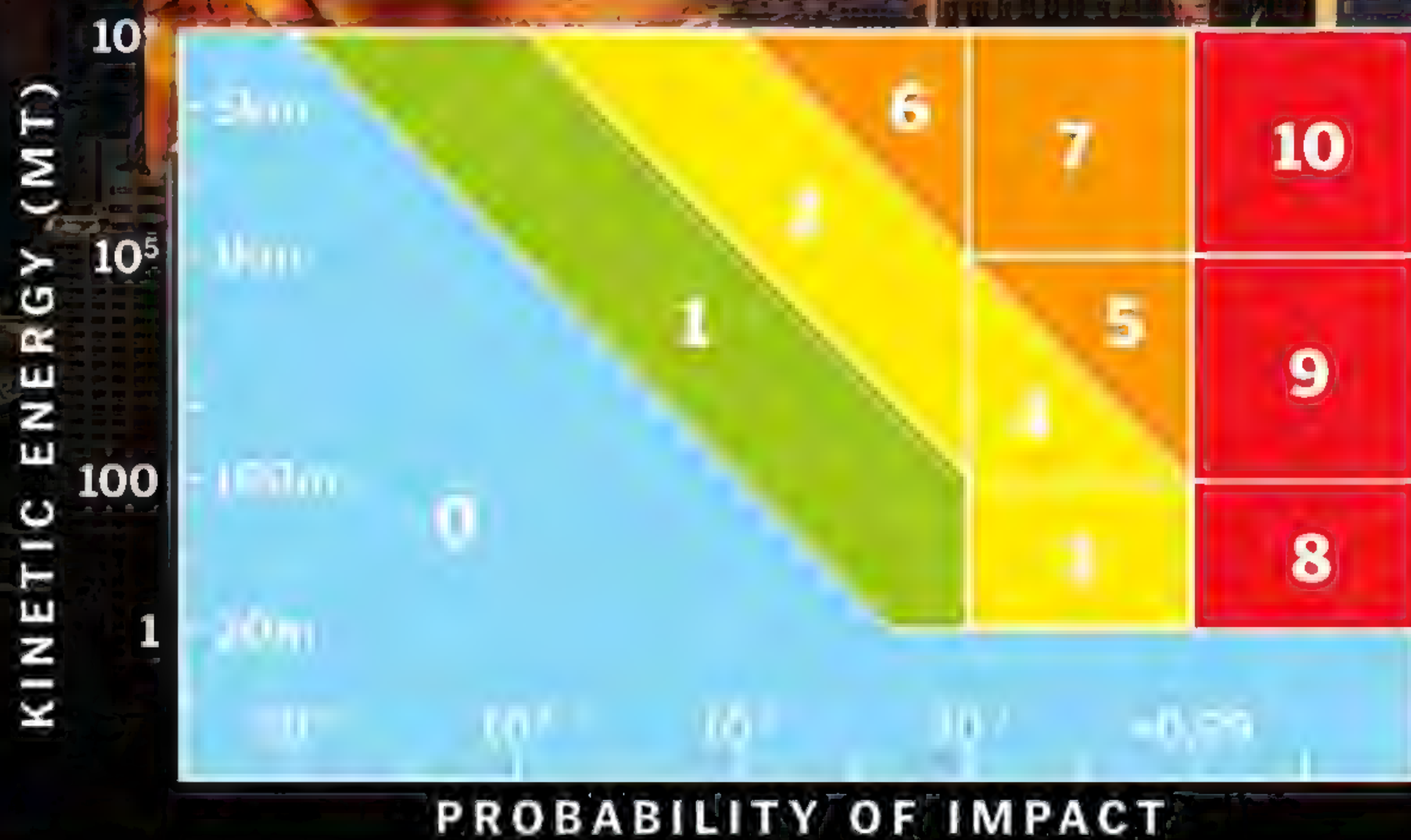
An asteroid is a piece of rocky debris left over from the formation of our Solar System that continues to orbit the Sun. Comets are similar, but they formed farther out in the Solar System and are thus likely to have considerably more ice than asteroids, as well as distinctive 'tails' of material. A meteor is an asteroid that enters our atmosphere but burns up, sometimes appearing as a shooting star. They are typically quite small and do not reach the surface. A meteorite is an asteroid or comet that does reach the surface and can be anything from a small rock to a huge crater-forming leviathan.

Meteors burn up in our atmosphere, whereas meteorites reach the surface



The Torino Scale

The Torino Scale is a way for us to rank how dangerous a potential impact with Earth could be. The scale ranges from 0 to 10 and is used by scientists to inform the public about the impending danger of an asteroid. The lowest ratings refer to objects that are either unlikely to hit us or are so small that they will simply burn up in our atmosphere. Those in the mid ranges refer to objects that are expected to come close to our planet so have a chance of hitting and are big enough that they could cause a considerable amount of damage. The upper end of the scale is reserved for objects that are certain to hit us and are so large that they could threaten life on our planet. Fortunately, at the moment we know of no objects that are above a 0 on the scale.



BLUE

There is essentially zero chance of a collision, or the object is too small to cause us any danger.

GREEN

The chance of a collision is very unlikely, so there is little cause for concern.

YELLOW

There is a one per cent or greater chance of an impact, which could cause localised destruction.

ORANGE

A very close encounter is predicted within decades, and governments may need to prepare for an impact.

RED

A collision with our planet is a certainty, and the object could threaten our civilisation on Earth.

completely clear. A possible explanation is that a large impact caused the planet to cool – the Hiawatha Crater may be evidence of this.

Looking far back into Earth's history we know that other meteorites have played a major part in our planet's evolution. Right back to the birth of our planet, 4.54 billion years ago, we think that meteorites were repeatedly slamming into the surface. Asteroids and comets are both rich in water, so a popular hypothesis is that these rocks were responsible for actually bringing the initial water to the Earth. We have also discovered that some space rocks are also rich in the ingredients of life, known as 'organics'. So life on Earth might have originated in a monumental impact long ago.

Then there's the Moon. Studying samples returned by the Apollo missions in the 1960s and 1970s, scientists were surprised to learn that Earth and its satellite shared similar chemical signatures. This led scientists to consider that the Moon may actually be a piece of Earth itself. This is known as the giant-impact hypothesis.

The idea is that a large object dubbed Theia, possibly the size of Mars, slammed into our planet about 4.5 billion years ago. This colossal impact ejected a huge amount of debris into Earth orbit that, over time, gradually coalesced into the Moon. Some questions remain, however, including how our planet would have actually survived such an impact. But at the moment this is the best theory we have to explain how the Moon formed, and it all started with a massive bang.

We are pretty sure that throughout Earth's history other, smaller impacts also had major effects on life. One of the most famous such events was the Chicxulub impact about 66 million years ago. A huge crater 180 kilometres wide in the Gulf of Mexico, it points to a large impact from an asteroid or comet up to 15 kilometres across, with a faint trace of this crater remaining today. A drilling project took place to try and directly sample this crater after it had been discovered in the 1990s. This event is thought to have brought to an end the

**"WE SEE
CRATERS
ALL OVER
THE PLACE"**



These scars of shocked quartz are only created by a shock on the scale of a meteor impact

Cretaceous period on Earth, with 75 per cent of life – including most of the dinosaurs – wiped out as a result of a chain of global catastrophes triggered by the impact.

Earth, of course, is not the only world in our Solar System that's been shaped by impacts. Our Moon is home to the South Pole-Aitken Basin, a vast crater roughly 2,500 kilometres in diameter. Another on Mars – called Utopia and measuring 3,300 kilometres across – is thought to be the largest of all. Throughout history each planet has been bombarded by objects, so Earth is no exception.

While the prospect of an asteroid hitting Earth might be terrifying – and there is plenty of evidence such events are catastrophic – we may very well owe our own beginnings to space rocks crashing into Earth. Thankfully, we know of no asteroid on a path with Earth that could result in another large impact event, but it's likely we will face such a prospect in future.

Studying the history of our planet and finding new craters like the Hiawatha Crater is vital to working out what effect these impacts have on our planet and what our prospects of surviving long into the future are. The very existence of life on Earth may one day rely on the scientists who examine the devastation of the past.



The dinosaurs (along with many other species) were wiped out by mega impact



10%

of known near-Earth asteroids are PHAs (potentially hazardous objects)

IN 2010, HUBBLE SAW THE AFTERMATH OF TWO ASTEROIDS COLLIDING

ESA's Hera mission aims to reach a binary asteroid in the 2020s

2,000 years

Average passage of time before a football pitch-sized meteorite hits Earth

25 metres

Smallest size for an asteroid to pass through Earth's atmosphere

Asteroids in similar orbits typically came from the same parent

1km

Minimum meteorite size for disastrous worldwide effects

SOME ASTEROIDS ARE RICH IN USEFUL METALS LIKE PLATINUM



**Beaverhead****Diameter:** 60km**Age:** 600 million years

On the border of the US states of Montana and Idaho you'll find this crater. The only remaining visible evidence for this crater comes from rock that was shocked by the impact force.

Sudbury Basin**Diameter:** 130km**Age:** 1.8 billion years

The third largest impact crater is the Sudbury Basin in Ontario, Canada, thought to have been caused by a meteorite up to 15km across.

Manicouagan**Diameter:** 100km**Age:** 215 million years

This ring-like lake found in Quebec, Canada, is thought to have been formed by a meteorite about 5km across hitting Earth.

Chicxulub**Diameter:** 180km**Age:** 66 million years

Believed to have wiped out the dinosaurs, the Chicxulub crater on the Yucatán Peninsula in New Mexico is the second largest impact crater on Earth.

10 BIGGEST IMPACTS ON EARTH

The largest craters that
can be found on the
surface of our planet



Kara

Diameter: 65km

Age: 70 million years

This crater in Russia may once have been 120km across, making it the fourth largest in the world before it was eroded and shrunk to its current size.

Popigai

Diameter: 100km

Age: 35 million years

Found in Siberia, the Popigai crater is the fourth largest in the world. It possibly caused the Eocene-Oligocene extinction event, when many marine organisms died.

Morokweng

Diameter: 70km

Age: 145 million years

An asteroid up to 10km across is thought to have formed this impact crater in the Kalahari Desert near the border of South Africa and Botswana.

Tookoonooka

Diameter: 55km

Age: 128 million years

Possibly measuring up to 66km across, this crater in South West Queensland, Australia, was first reported back in 1989.

Vredefort Dome

Diameter: 300km

Age: 2 billion years

Found in South Africa, this is the largest known crater on Earth. Although much of it has eroded away, the remaining structure is called the Vredefort Dome.

Acraman

Diameter: 90km

Age: 580 million years

Found in South Australia, this impact crater contains a lake that's 20km across known as Lake Acraman. The discovery of the crater was first reported in 1986.



TRANSPORT

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Dip below the waves in a private submersible

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The vehicles that can hoover up rubble

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Hop aboard this state-of-the-art polar explorer

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Warfare will never be the same again

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Super-sucking
trucks



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mobile





UNDERWATER EXPLORERS

Welcome aboard! Prepare to dive into the world of the private submersibles taking us to incredible new depths of the ocean

James H. Baker



The oceans serve as Earth's largest habitat and are home to a phenomenal array of life. As well as discovering this rich diversity, exploring the depths allows us to peel back the curtain on another world.

Mere centimetres beneath the waves corals bloom, fish graze, cephalopods hunt and crustaceans battle. But few of us ever get the opportunity to venture deeper, down where the pressure is too much for our unprotected bodies to endure and the light fades away, leaving the water an inky black. At these extreme depths fantastical creatures begin to appear. First the swordfish, then the angler fish, then for the lucky few, the elusive giant squid. Until recently a private citizen could

do little but dream about seeing such sights for themselves. But there are now some astounding vehicles that have unlocked the potential of the deep blue. We are in the era of the private submersible, which not only lets civilians peruse the depths at their leisure, but lets them do it in style.

These manned vehicles are escorted to their dive sites by other vessels, but once set loose under the water they are able to roam independently. Many of the companies that are selling such technologies also offer pilot training, meaning the private

operator can take full control of their new vehicle. The variety already on offer is

astounding. In this feature we'll uncover shallow pleasure cruisers, hardier research vessels and even a submersible that can reach the very deepest point on the ocean floor. Yes, that's right: you can now buy a vehicle that will allow you to replicate a feat that has so far only been achieved by three people in history. So read on and get saving, because these pleasures don't come cheap.

But it'd be hard to argue that they aren't worth the money.

"At these extreme depths fantastical creatures begin to appear"

Bottom dweller

Meet the Triton 36000/2, an emerging veteran of the deep

The latest trialled and tested Triton model is a juggernaut of a submersible. Built to endure the punishing pressures of the oceans depths repeated times, the vehicle is currently undergoing a pilgrimage to prove its mettle.

Under the control of a private owner, Triton is touring the world on a quest to escort its pilot to the deepest point of the world's five oceans. As the sole manned submersible of the Five Deeps Expedition, at the time of writing Triton has

already touched down at the bottom of the Atlantic, Southern and Indian oceans, and it will tackle the Pacific and Arctic depths later this year. Upon its completion of this record-breaking mission the submersible, its launch vessel and accompanying craft will become available to a private owner. They can all be yours for just \$48.7 million (around £37.7 million).

TRITON 36000/2

DEPTH RATING:

11,000m

MAX CREW:

2

LIFE SUPPORT (HRS):

16 (standard)

96 (emergency)

MAX SPEED:

3km

Safety measures

Multiple redundant ascension systems and 12 separate batteries ensure that the Triton will always be able to return to the surface.

Viewports

Carefully positioned acrylic viewports allow the crew unobstructed forward and downward views of their surroundings.

Protection

A 90mm-thick and 99.933 per cent truly spherical hull protects the crew from a crushing 1,100 bars of pressure.

Freedom of movement

The submersible can easily ascend, descend and pivot with the help of versatile motors.

Sampling

A multi-axis manipulator arm allows the crew to physically probe and collect samples from the external environment.

Efficient design

The Triton's focus on simplicity allows it to be easily piloted and permits repairs while at sea.

For the long-haul

Leather-bound seats keep the crew comfortable throughout their 8- to 12-hour-long missions.

Record-breaker

In March 2012, film-maker James Cameron touched down at the deepest point in the world's oceans - near the very bottom of the Mariana Trench. Just two others had achieved the feat before, and Cameron was the first pilot to make the descent solo. Cameron was fixated in the days of the old Deepsea Challenger submersible, which was able to handle variable risks. The vehicle itself was an engineering marvel, requiring the team to keep a close eye on a range of issues - including the vehicle's ascent - and develop several backup contingency plans to prevent working threats. Equipped with a reliable array of 24 red laser lights of 140W, two battery banks and 40 batteries, Challenger was able to bring a false-of-mortality back to the surface. The mission was a triumphant success.



James Cameron's record-breaking solo descent in the Deepsea Challenger submersible

© Getty

Ocean tourer

Equipped with two powerful cameras, the Aurora 6 boasts two richly detailed 1080p HD video cameras, a wide-angle 180-degree viewfinder, and even a 360-degree view of the surrounding environment. The Aurora 6 is designed to be a versatile, multi-purpose submersible that can be used for a variety of tasks, from scientific research to commercial exploration. The Aurora 6 is a 100% reusable and expandable submersible.

The Aurora 6 is a 100% reusable and expandable submersible

© Seamagine

SEAMAGINE AURORA 6

DEPTH RATING:

1,000m

MAX CREW:

2

LIFE SUPPORT (HRS):

8 (standard)

24 (emergency)

MAX SPEED:

3km





Underwater luxury

Cruise along in unrivalled splendour beneath the ocean tides

Sometimes a massive yacht just isn't enough. For those fortunate few who are lucky enough to tour the seas on their own private vessels, a pleasure cruise beneath the waves undoubtedly holds as much appeal as the sights to see above it. Fortunately, the NEYK submarine is ready and able to fill this purpose. With a modular design that can be easily modified to fit its owner's specifications and desires, the NEYK can host a crew of up to 20 people. The airplane-style hull is also peppered with viewports, allowing the passengers to sit back and drink in the sights hidden beneath the waves.

Rising up

The submarine can return to the surface by inflating four air balloons attached to the hull.

Sensors

Extra lights, cameras, night-vision equipment and radar can all be equipped to the NEYK's dome.

360° vision

The pilot can gain a wide view via the top viewport.

Surveying

A high-resolution 3D sonar scanning system can complement the viewports to help the pilot visualise the vessel's surroundings.

Portability

A retractable undercarriage allows the NEYK to ascend and descend ramps from launch vessels under its own power.

Sea views

The nose can be modified to a glass front to improve passengers' viewing.

Modular comfort

The heavily customisable interior can be altered to accommodate a large crew, additional furniture or extra equipment.

Streamlined

Its teardrop structure helps the slender vessel surge through the water at up to 15kn.

Thrust

Two powerful 200kW electric motors quietly drive the propellers, providing the crew with a tranquil cruise.

NEYK LUXURY SUB

DEPTH RATING:

30m

MAX CREW:

20

LIFE SUPPORT (HRS):

120

(12 passengers)

MAX SPEED:

15kn

(11kn surfaced)

TRITON 1000/2

DEPTH RATING:

30m

MAX CREW:

2

LIFE SUPPORT (HRS):

10

MAX SPEED:

30kn

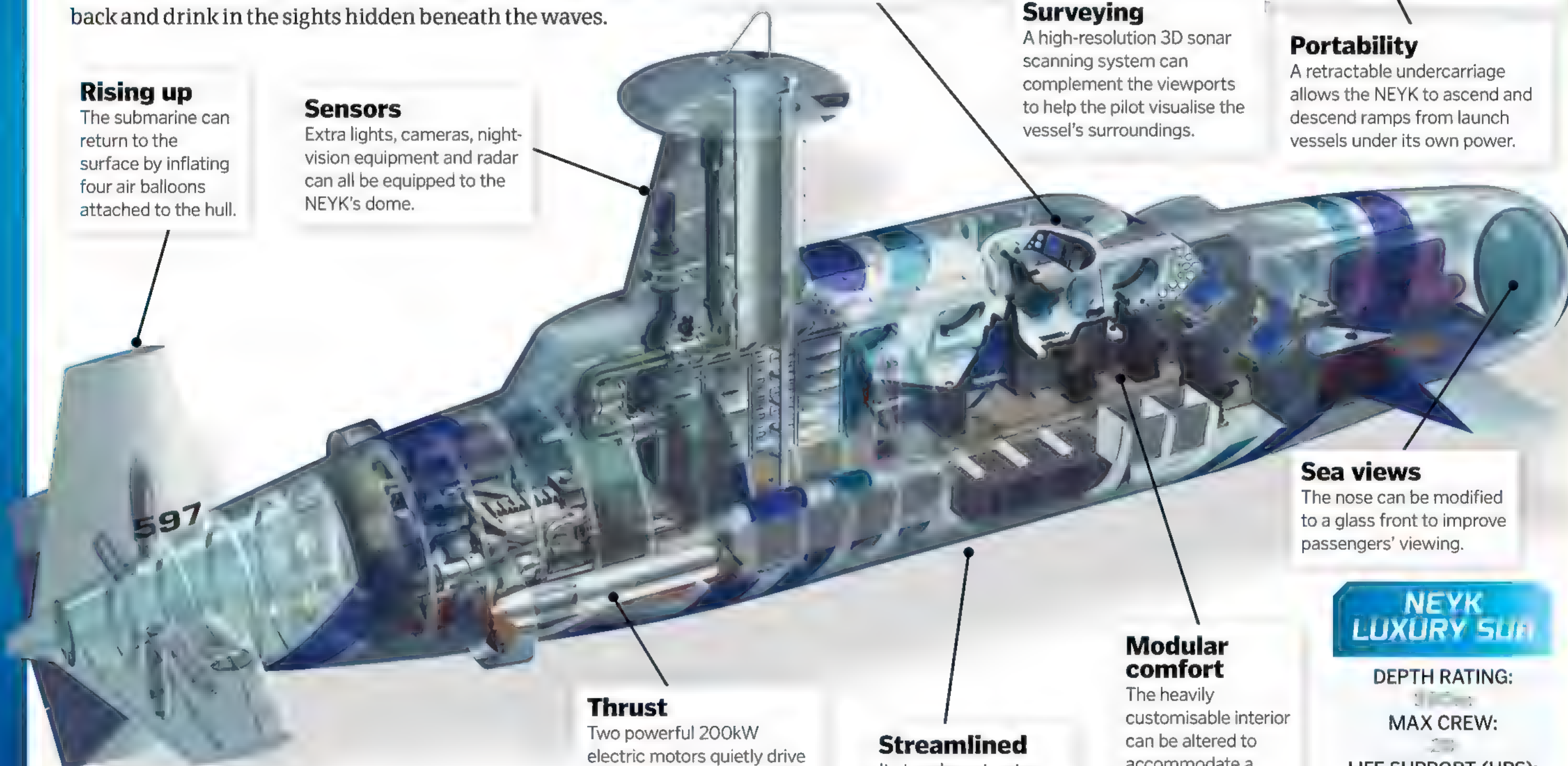
Shallow dive

You needn't leave for underwater to enjoy the splendour of marine life. As any keen diver or scuba diver would testify, the best diving is done within 100m of the surface. The Triton 1000/2 is a shallow water submersible that allows you to explore the underwater world in comfort and safety. The Triton 1000/2 is a shallow water submersible that allows you to explore the underwater world in comfort and safety. The Triton 1000/2 is a shallow water submersible that allows you to explore the underwater world in comfort and safety.



Enjoy all mod cons while exploring underwater

© OCEAN SUBMARINE



Deep-water researcher

The Titan is an innovative deep-sea science vessel



Sports sub

he says, the feeling from any single time refers back to take it to a greater extreme. For this time $5 \leq x$, retroubling, whatever that resembles a word is a turned-around time, a counter out of a chain, more fullness.

[illegible]

U-BOAT WORK HIPER SUB

DEPTH RATING:

100

MAX CREW:

22

LIFE SUPPORT (HRS):

5

MAX SPEED:



Data collection

Multiple 4K cameras, data tablets and a laser scanner enable the craft to capture deep-sea data for scientific research.

Sight inspection

The Titan's arsenal of equipment and large viewport make it perfect for surveying underwater wrecks.

The Cyclops

Titan boasts the largest viewport of any deep-sea submersible, providing immersive views for its crew.

Easy docking

Integrated landing provisions allow the submersible to dock after a dive without assistance from a scuba team.

**OCEANGATE
TITAN**

DEPTH RATING:

MAX CREW:

1

LIFE SUPPORT (HRS):

()

... ()

MAX SPEED:

Figure 1

Layers of the oceans

Wiley InterScience®
DISCOVER SOMETHING GREAT

0-200m

The shallows of the ocean are known as the Epipelagic or the 'Sunlight' zone.

200-1,000m

Home of the 'Twilight zone', referred to as the Mesopelagic zone by ocean scientists.

1,000-4,000m

This gloomy region is the last to be reached by any sunlight.

4,000-6,000m

The Abyssopelagic or simply 'Abyssal' zone is in perpetual darkness.

6.000m+

The world's deepest oceanic trenches are an alien place that can be reached only by extremely specialised vessels.



Uplifting earth

How hydrovacs safely excavate the ground without damaging pipes

Storage

Sucked-up debris is dropped in the storage tank, typically capable of holding around 12m³ of material, with sensors alerting operators when the tank is full.

Heating

In order to break apart hard ground such as frozen earth or dense clay, an onboard boiler can heat the water.

Vacuum

Lifting rocky debris requires a lot of suction power. The internal vacuum pump can extract almost 10,000 cubic metres per hour.



Boom

A retractable telescopic boom is used to suck up the broken ground, moving it to be stored in the tank. The boom can reach around eight metres away from the vehicle.



Digging

As pressurised water breaks up the ground, the boom collects the broken debris. Hydrovacs can access several metres into the ground for extraction.

Water wand

Water is manually delivered to the target via a pressurised wand at speeds of around 80 litres per minute and 3,000 PSI.

Super-sucking excavator trucks

How do these hydro-vacuum vehicles suck up tons of rubble?

Long gone are the days of manual digging on construction sites with the introduction of these mammoth vacuum vehicles. Commonly known as hydrovac trucks, these purpose-built machines utilise hydro-vacuum excavation to break down the dense rock. There are two main components to achieve this: highly pressurised water is jetted onto the ground to break it apart and form a slurry. Simultaneously a vacuum boom sucks up the slurry and debris as it goes. The remains are stored in the truck's vast containment unit, until they're driven to a dumping site and removed from the bowels of the vehicle. Hydrovac trucks use different methods to expel the rocky remains, including a hydraulically lifted tank to tip out rubble and water, or a moving wall within the tank to push the ground out.

One of the biggest problems with digging underground is the potential for compromising

water mains, communication lines, gas pipes or electrical cables. The hard tools used in manual digging are a particular threat to this underground infrastructure. However, as hydrovacs only use pressurised water to excavate, the risk of breaking a pipe or severing a cable is significantly reduced.



Hydrovacs are used to access underground infrastructure, including cleaning US storm drains

To the rescue

Although hydrovacs are used for everyday maintenance including, they can also offer a helping hand in times of crisis, in particular landslides. These occur for several reasons, often when earthquakes or heavy rainfall loosen the ground – and the results can be extremely devastating.

In early 2018 a landslide occurred in California, depositing hundreds of tons of debris onto a highway. Hydrovac trucks, along with many other maintenance vehicles, arrived at the scene and used their vacuuming abilities to remove the mud and rubble, redistributing it to another site.



Hydrovac trucks are used to clean up debris from landslides and other disasters

Crossing the ice

How does this ice mobile skate across Antarctica's icy terrain?

Green fuel

The CIV uses bio-fuel to evaluate its performance under extreme cold conditions.

Lightweight

Zooming over the ice, the CIV only weighs 360kg, so it is light enough to be manually hauled if need be.

Engine upgrade

Putting power into the propellers is a supercharged 1150 BMW engine.

Triple-ski system

Three skis facilitate the vehicle's glide across the ice. Independently suspended, engaged spikes allow the CIV to brake effectively.

Top speed

Three blade propellers enable the CIV to reach a maximum speed of 135kph.

Polar-exploring ice mobile

The bio-fuel-powered vehicle that can zip across Antarctica to reach the South Pole

In 2010 a team of researchers and engineers set out to achieve the first there-and-back vehicle crossing, nearly 4,000 kilometres, across Antarctica. Leading the assembly of research transport and a mobile laboratory was the first bio-fuelled machine to reach the South Pole: the Lotus Concept Ice Vehicle (CIV). It was also known as the Winston Wong Bio-Inspired Ice Vehicle in honour of the project's sponsor, Professor Winston Wong.

At its core, the functionality of the CIV is to aid the research conducted on the ice sheet. With built-in radar, the CIV's sensors can penetrate the ice and detect any surprises within it, such as crevasses, before the rest of the team encounter them. Mounted on three skis and thrust across the ice by way of three propellers, the CIV is able to navigate the unpredictable terrain of the Antarctic surface. One of the predominant reasons for the creation of the

vehicle was to monitor and research the chilling effects of the environment on the CIV's bio-fuel reserves. As it's one of the regions of the planet most affected by pollution, green or zero-emission solutions for human activity at the Antarctic are paramount.



The Lotus Concept Ice Vehicle is 4.5 metres wide and 4.5 metres long

Venturi Antarctica

Almost two years after the CIV that crossed Antarctica, a new generation of vehicles have been designed to conquer the continent's harsh conditions, most notably the Venturi Antarctica.

With the final model unveiled at the Prince's Palace in Monaco in late 2018, the two-ton vehicle is set to shift the ice itself by 100m. The Venturi Antarctica is the first motorised, self-driving, self-repairing vehicle equipped with an AI-powered repair system that can patch a 10cm wound at around 20 kilometres per hour. It's set to monitor the largest icebergs on the continent, the Venturi Antarctica is built on a self-repairing modular chassis, one can withstand temperatures as low as minus 50 degrees Celsius.

With a range of 15,000km, these vehicles will be used to study the ice sheet's future prospects, difficult to access. The Antarctica completed a test run in Canada in February 2019.



Venturi Antarctica is a self-driving, self-repairing vehicle that can patch a 10cm wound at around 20 kilometres per hour.



ROBOT

Words by **Scott Dutfield**



Drones have been designed to act as both surveillance and support aids for soldiers on the ground

WARS

THESE ARE THE MACHINES THAT WILL DOMINATE
THE BATTLEFIELD ON THE FRONT LINES OF THE FUTURE

In November 2018, the UK's Ministry of Defence conducted the largest military robot exercise to date. Known as Exercise Autonomous Warrior, over 70 future technology examples were tested for their ability to support soldiers in conflict areas. More than 200 military personnel attended the event to test the suitability of these robots to join their ranks. From drone detectives to autonomous armed vehicles, *How It Works* travelled to a military base in Salisbury to discover which robots we might see on the front lines in the future.



Milrem Robotics have created an unmanned guided vehicle for autonomous resupply



The Marionette control system removes the need for human operators and converts existing tanks into remote-control robots





REMOTE-CONTROL SOLDIERS

Human soldiers put their lives on the line in military conflict. However, collaboration between robotics engineers has resulted in the creation of mechanical soldiers to take some of the heat off their human comrades. A robot team known as TITAN Strike and Sentry, which has the potential to reach areas inaccessible to foot soldiers, has been created by Milrem Robotics and QinetiQ. Strike is armed with a machine gun and cameras, while Sentry acts a guide, using sensors and cameras to track targets before its partner goes in on the offensive. Both vehicles can be controlled remotely or via a preprogrammed route. The modular base unit housing the artillery is known as THeMis and can also be used as a resupply device due to its autonomous abilities. Sensor and mapping technology enable the robots to travel between base and battlefield delivering ammunition, medical and resource supplies.

Engineers have also created a way to hijack existing weaponry to create a new kind of robot. The British Warrior FV510 tank, which first entered service in 1988, has had a robotic overhaul with the Marionette universal system. Like a puppet on a string, this control system can be hardwired into the military tank, transporting control of the mammoth vehicles to soldiers several kilometres away.

SPY IN THE SKY

Drones have become a revolution in many different industries, but now unmanned aerial vehicle (UAV) developers Threod Systems have created a heavy-duty one designed to act as an

The Black Hornet PRS can fly 2km at speeds of up to 21.5kph



The TITAN Strike and Sentry work together to track targets and engage the enemy

Military personnel can control Strike remotely to scope out battlefields

army's eyes in the sky, along with a delivery system for those on the ground. The KX-4 LE TITAN is a drone with a plug-and-play payload, thanks to a lift capacity of around six kilograms. Aerial mapping sensors, cameras and gimbals are some of the modular options that attach to it, allowing it to survey an area, track targets and lock-on up to five kilometres away. Also offering back-up from the skies, the TITAN can drop resources such as life jackets and even deliver stun grenades for combat support. Having eyes in the sky can offer unique tactical support, but if they're spotted, there are many ways to take them down, from frequency-emitting drone guns to actual bullet-loaded ballistics.

Stealth is key to staying airborne. Only 16.8 centimetres long, the Black Hornet PRS has been described as a form of nano surveillance for its ability to quietly zip ahead of the troops. Resembling a toy helicopter, this pocket-sized UAV is deceptively high-tech. It is equipped with advanced electro-optical and infrared cameras and sensors to offer the operators a clear view of the threats ahead.

"The TITAN can drop resources such as life jackets and even deliver stun grenades"



The Throwbot 2 can clear obstacles up to 5cm tall

Robotic infiltrator

Designed for withstanding repeated drops of 5.1 metres by its weight, the Throwbot 2 is a compact robot (unmanned) meant able to escape fast potential threats without the need for human intervention. Equipped with a colour camera, microphone and infrared illuminator, this tiny robot can relay live video footage and real information back to a handheld monitor. It provides a better picture of what it finds. To maintain its stealthy nature, Throwbot is around 25 centimetres in length and weighs less than 50 grams. It is a one-way robot (about the same as a radio) (cannot be used to receive signals).



The Black Hornet PRS is almost silent, making it perfect for use in combat

JACK OF ALL TRADES

THERE'S ONE MACHINE THAT CAN SEEMINGLY DO IT ALL - THE THEMIS IS ABLE TO CARRY OUT SEVERAL TASKS IN THE FIELD THANKS TO ITS MODULAR DESIGN

Landmine

Using the GroundEye module, the THEMIS can detect and mark landmine landing sites in the field.

Scout

As robotic eyes on the ground, the GroundEye module can detect and mark landing sites in the field.

Detective

Equipped with the Pegasus Multiscope, this module can view areas difficult to reach by foot, and with built-in sensors it has the ability to monitor heat signatures and air particulates.

Weapon

As a robotic soldier, this weaponised module can lock on to targets and fire remotely.

Bomb defuser

The THEMIS GroundEye has a module system that can detect explosive IEDs buried beneath the ground.

Fire fighter

Swapping a gun for a hose, it can be used to direct water to the higher levels of a burning building.

Medic

Supplies aren't the only thing this robot can transport. As a medevac module, the THEMIS can be used to load a stretcher carrying a wounded soldier, driving them away to safety.

Carrier

Fundamentally the THEMIS is a supply vehicle, enabling resources to reach soldiers at base or in the field without risking more lives during battle.





On board the HAWK

The dual-control training jet that helps the next generation of pilots prepare for combat

Words by **Scott Dutfield**

Getting into the cockpit of a jet engine aircraft for the first time is a daunting prospect for any trainee pilot. After spending years learning the theoretical physics and basics of flying, the Hawk is the next stage in their training and their first real venture into the skies in a working military jet.

The Hawk has played a key training role within the Royal Air Force (RAF) since the 1970s. Originally designed and constructed by Hawker Siddeley Aviation Limited (now known as BAE Systems) in 1971 and first flown in 1974, the Hawk promised a more agile way to fly. It replaced the Folland Gnat, a plane similar in weight and size. However, the Gnat's cockpit only offered a single

seat, leaving inexperienced pilots to fly solo. The Gnat saw the end of its training career in 1979 when the new, purpose-built Hawk T1 swooped in to take over.

What makes the Hawk unique for training the next generation of RAF pilots are its dual-control capabilities. Similar to the dual-control cars used by driving instructors, the two-man tandem cockpit enables a teaching pilot to sit behind their student and intervene when needed. For teaching the basics, the jet's cockpit is relatively unchanged since the plane's introduction to the Air Force. Pilots rely on dials, gauges and the view through the glass roof to navigate and fly the plane. However, BAE

Systems has integrated multi-functional digital displays in the newer model, the Hawk T2.

Offering an introduction to fast jets, the Hawk is designed to reach Mach 0.88 during flight and Mach 1.15 during a dive. The Mach number relates to the jet's speed when compared to that of sound (equal to Mach 1), so the Hawk can manoeuvre at speeds known as transonic, paving the way for pilot training on supersonic jets such as the F-35 Lightning II.

Although predominantly used as training jet, the Hawk has proven itself as a combat aircraft and has also been used for reconnaissance and surveillance. Currently, around 1,000 aircraft have been sold to 18 countries across the globe.



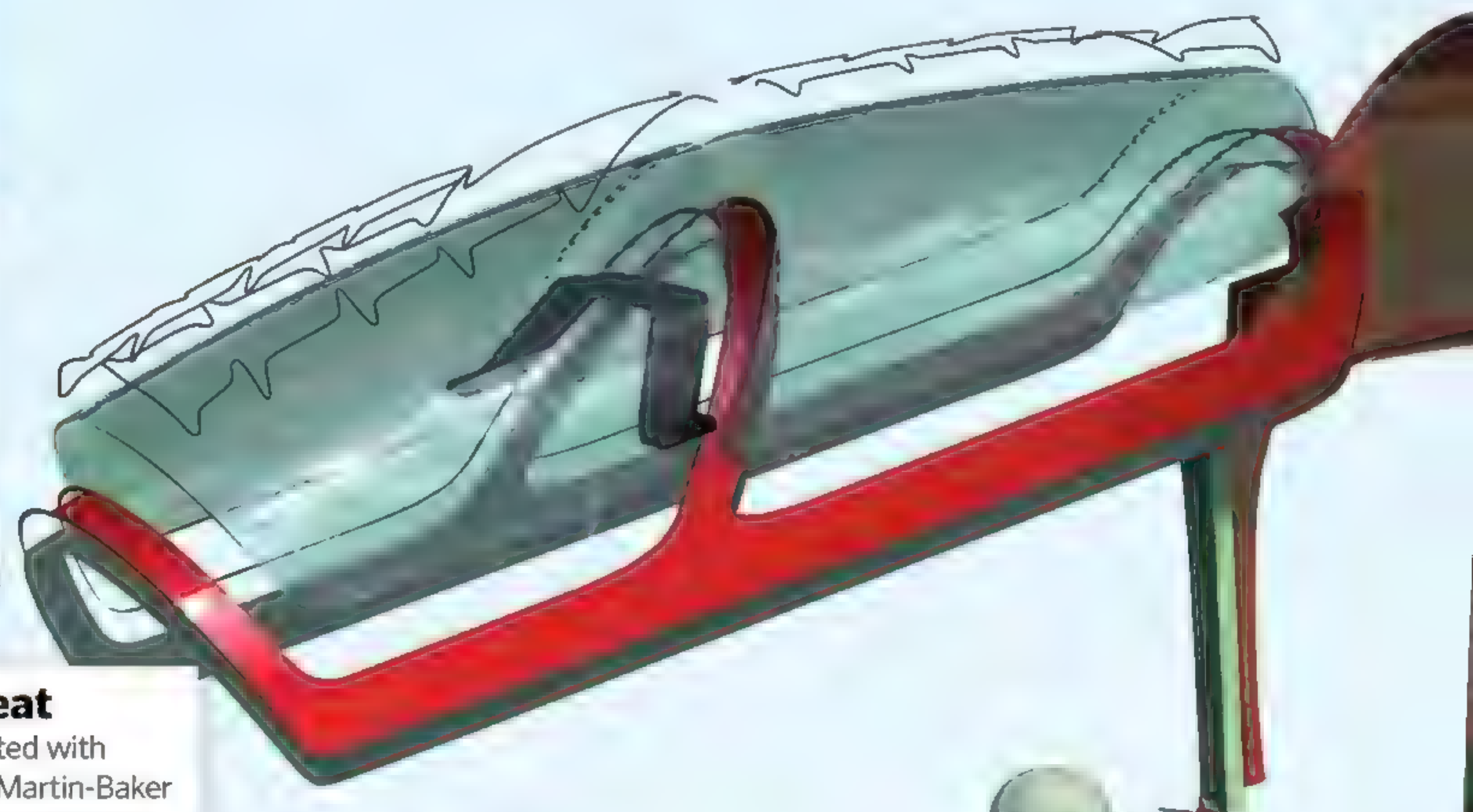
Aerial acrobats

Though they triumph as a training jet, the Hawk is most recognised as the type of plane seen flying in formation during a Red Arrows display. Originally sporting a black coat of paint, the newly introduced Hawk T1 had a red makeover upon joining the ranks of the Royal Air Force Aerobatic Team in 1979. Debuting synchronised sky routines a year later, the Hawk T1 proved its ability to perform stunning displays.

These gravity-defying stunts, however, can be limited by the weather. In order to carry out the iconic loops, the cloud base needs to be above 1,700 metres so the aircraft avoid entering it and disappearing from sight. If the clouds are lower than that, they're limited to rolling displays, flypasts and steep turns.

**Ejection seat**

Each plane is fitted with rocket-assisted Martin-Baker Mk.10 ejection seats for use in an emergency.



Inside a RED ARROW

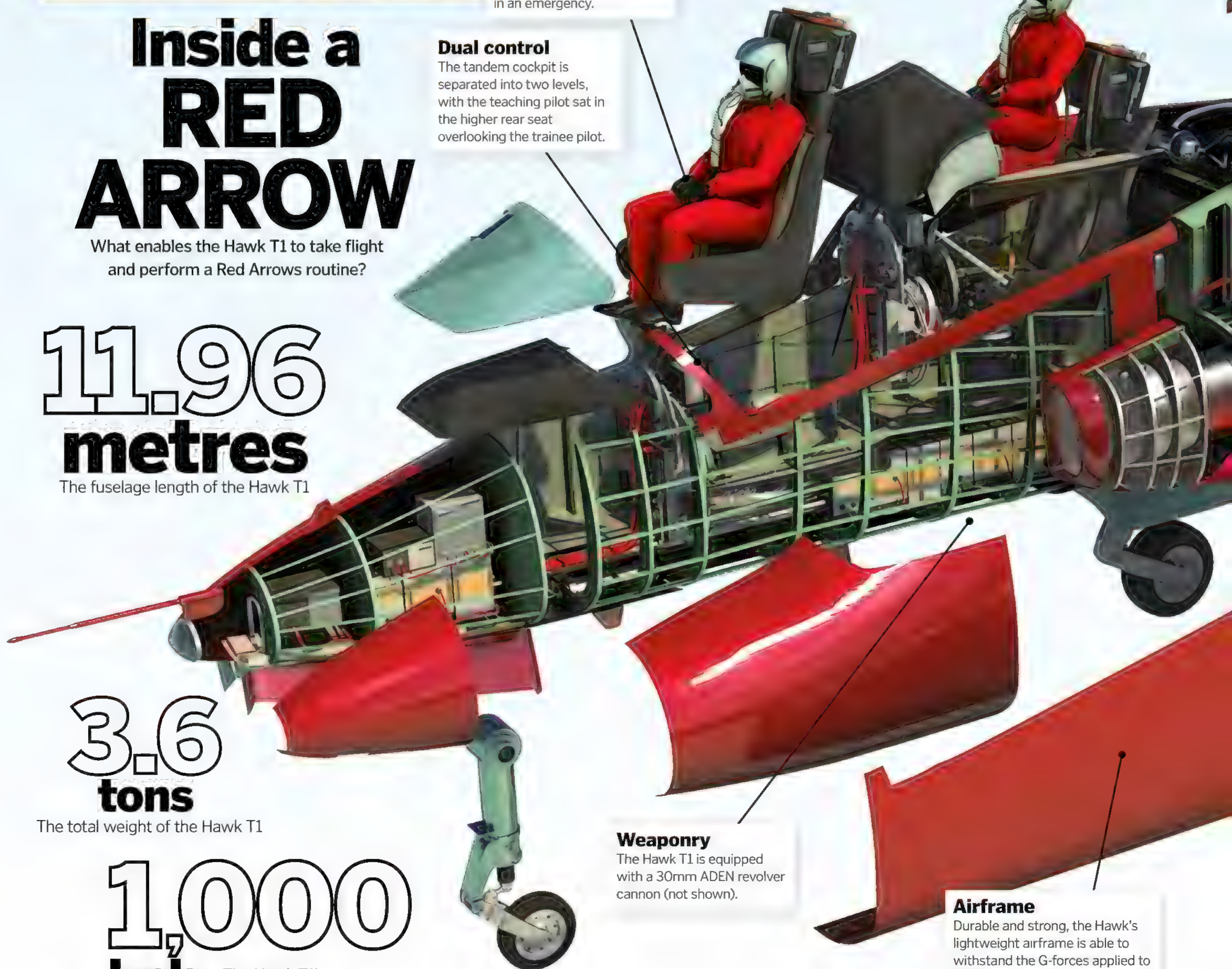
What enables the Hawk T1 to take flight and perform a Red Arrows routine?

Dual control

The tandem cockpit is separated into two levels, with the teaching pilot sat in the higher rear seat overlooking the trainee pilot.

11.96 metres

The fuselage length of the Hawk T1



3.6 tons

The total weight of the Hawk T1

1,000 kph

The Hawk T1's maximum speed

Weaponry

The Hawk T1 is equipped with a 30mm ADEN revolver cannon (not shown).

Airframe

Durable and strong, the Hawk's lightweight airframe is able to withstand the G-forces applied to the plane during manoeuvres.

3.99
metres

The height of the Hawk T1

"A Rolls-Royce Turbomeca Adour jet engine powers the Hawk, producing around 2,400kg of thrust"

Smoke trail

Coloured dye is made by injecting diesel into the path of the jet engine's exhaust, vaporising on contact and producing plumes of smoke.

Power house

Housed at the rear of the plane, a Rolls-Royce Turbomeca Adour jet engine powers the Hawk, producing around 2,400kg-force of thrust.

Aerodynamic

The sleek tail design of the Hawk facilitates the smooth turns and dives during a performance.

2.5
tons

Maximum missile payload

Strong wing

The T1 is supported with cantilever wings, with a total area of 16.69m².

The Hawk T1 is also equipped with two Sidewinder air-to-air missiles

Since 1979, the Hawk T1 has been the aircraft used in Red Arrows displays across the globe

9.39
metres

The wingspan of the Hawk T1





How cement-mixing vehicles work

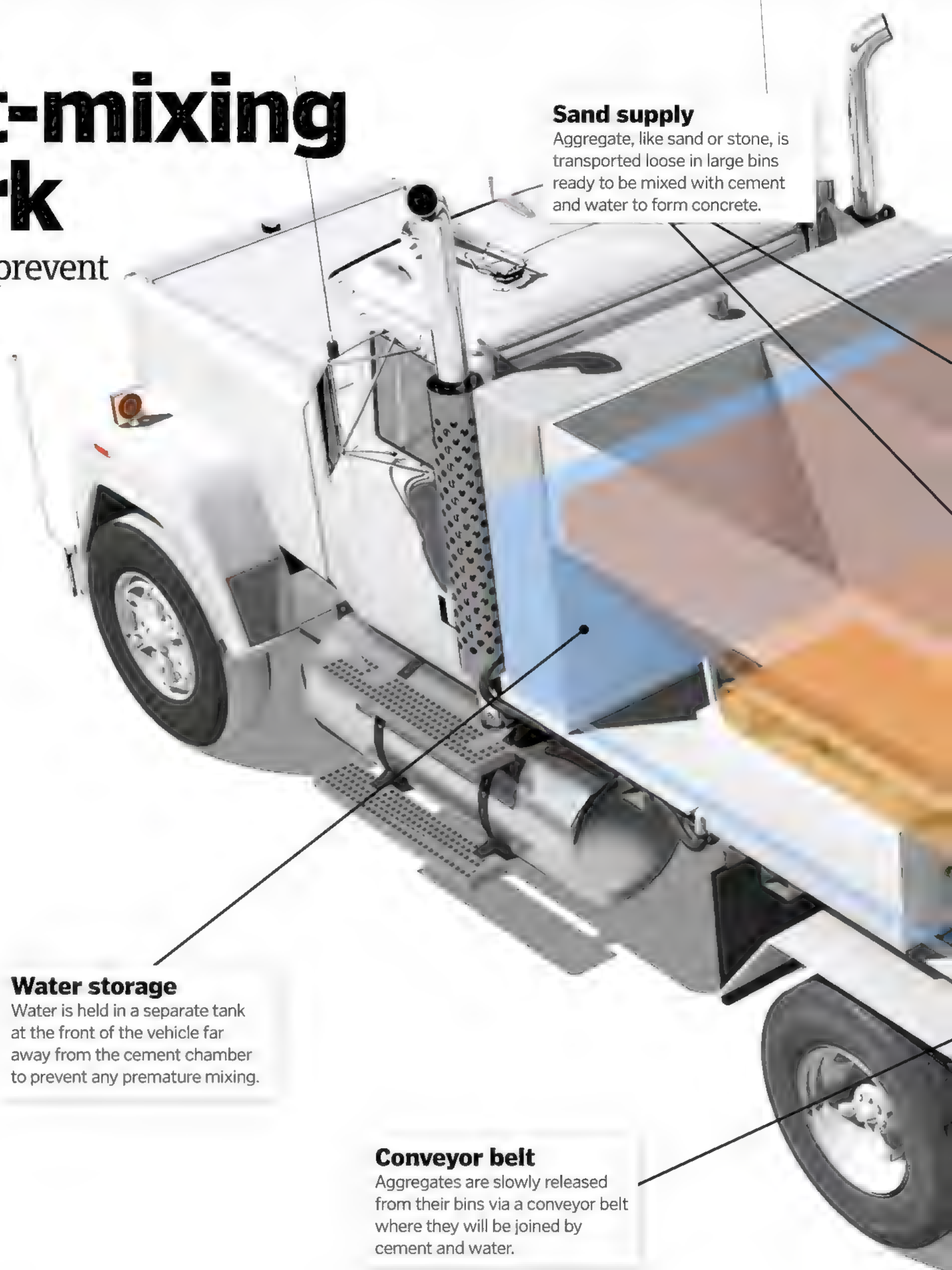
How do these concrete transporters prevent their load from turning rock solid?

Concrete mixer trucks, delivering vital raw material, bear the weight of around 13,500 kilograms of cement. These vehicles have the repetitive task of continually cycling its contents. A cocktail of aggregate (sand or stones), cement and water are hurled into the drum-shaped rotating barrel at a concrete-production plant. Interior fins, shaped and arranged like a screw, fold the ingredients together. During its journey from the production plant to construction project, the drum is constantly turned by an external motor.

Once it reaches its final destination, hydraulics lift the drum and its cement concoction, allowing gravity to pull the freshly formed concrete down a delivery spout. The mixing fins also lend a helping hand, spinning in the opposite direction to that of the mixer, to force the material out of the drum.

This method of concrete creation comes with a race against the clock. Known as 'batch mixing', this traditional way of transporting a pre-made product comes with a quick expiry time: There is a short window of opportunity to distribute the solidifying substance before it sets and hardens, typically around 90 minutes. This constraint is one of the reasons manufacturers have created a portable concrete factory in the form of volumetric cement mixer trucks.

These building behemoths carry uncombined ingredients to a construction site and form fresh concrete at the touch of a button. Using a built-in micro production line, the main ingredients are fed to a mixing auger (rotating screw) via conveyor belts and pipes. The result is fresh, made-to-order, fluid concrete, ready to be laid.



Sand supply

Aggregate, like sand or stone, is transported loose in large bins ready to be mixed with cement and water to form concrete.

Water storage

Water is held in a separate tank at the front of the vehicle far away from the cement chamber to prevent any premature mixing.

Conveyor belt

Aggregates are slowly released from their bins via a conveyor belt where they will be joined by cement and water.

Mobile concrete factory

How do volumetric mixer trucks turn sand and cement into fresh concrete?

Paving the way

The original mechanics of the portable concrete mixer have remained relatively unchanged over the centuries, almost 100 years on. Taking cues from the horse-powered machines, the first motorised concrete mixers sprang into action in the early 1900s. The first patent application for a vehicle-driven mixer is believed to have been filed by American inventor

Stephen S. Snyder back in 1916 and although the design is reminiscent of today's vehicles, the patent was denied. Later iterations came from inventors such as John F. Baker, who successfully patented the first concrete-mixer truck in 1925. Following the same principles of modern-day machines, Baker's mixer was also designed to transport over 100 cubic yards of concrete.

©Getty

Essential to the construction industry, concrete-mixer trucks continually spin their contents to prevent it setting in transit



Cement mix

Essential to concrete creation, cement is made from grinding down rock, such as limestone, shells and chalk.

Aggregates, such as sand or gravel, and water are used to form concrete

Pumping power

To deliver concrete to those hard to reach places, such as at the top of a building, mobile mixers call upon the help of another vehicle known as a concrete pump truck. Acting as an extension cable for concrete, these vehicles often come with an extendable robotic arm or boom to maximise the distance it can be poured. Working in unison, the drum-shaped mixer ejects its concrete cargo into the metal grate at the rear of the pump truck. A hydraulic pump system then forces the fluid material through a large pipe running along the boom arm and out through a delivery hose, which is close to the ground.



Concrete mixers and pumps work together to distribute the concrete around a construction site

First mix

A short auger spins to combine the dry ingredients of the concrete mixture (aggregate and cement).

Adding water

By delivery through internal piping, water is washed over the dry cement mixture to begin the process of concrete creation.

"This method of concrete creation comes with a race against the clock"

Mix well

The main auger mixes all concrete ingredients, repeatedly turning to completely combine them.

Ready-made concrete

Fresh off the conveyor belt, viscous concrete flows out of the delivery spout to pour directly on-site.

Volumetric concrete mixers are growing in popularity for their ability to make large amounts of concrete on a building site





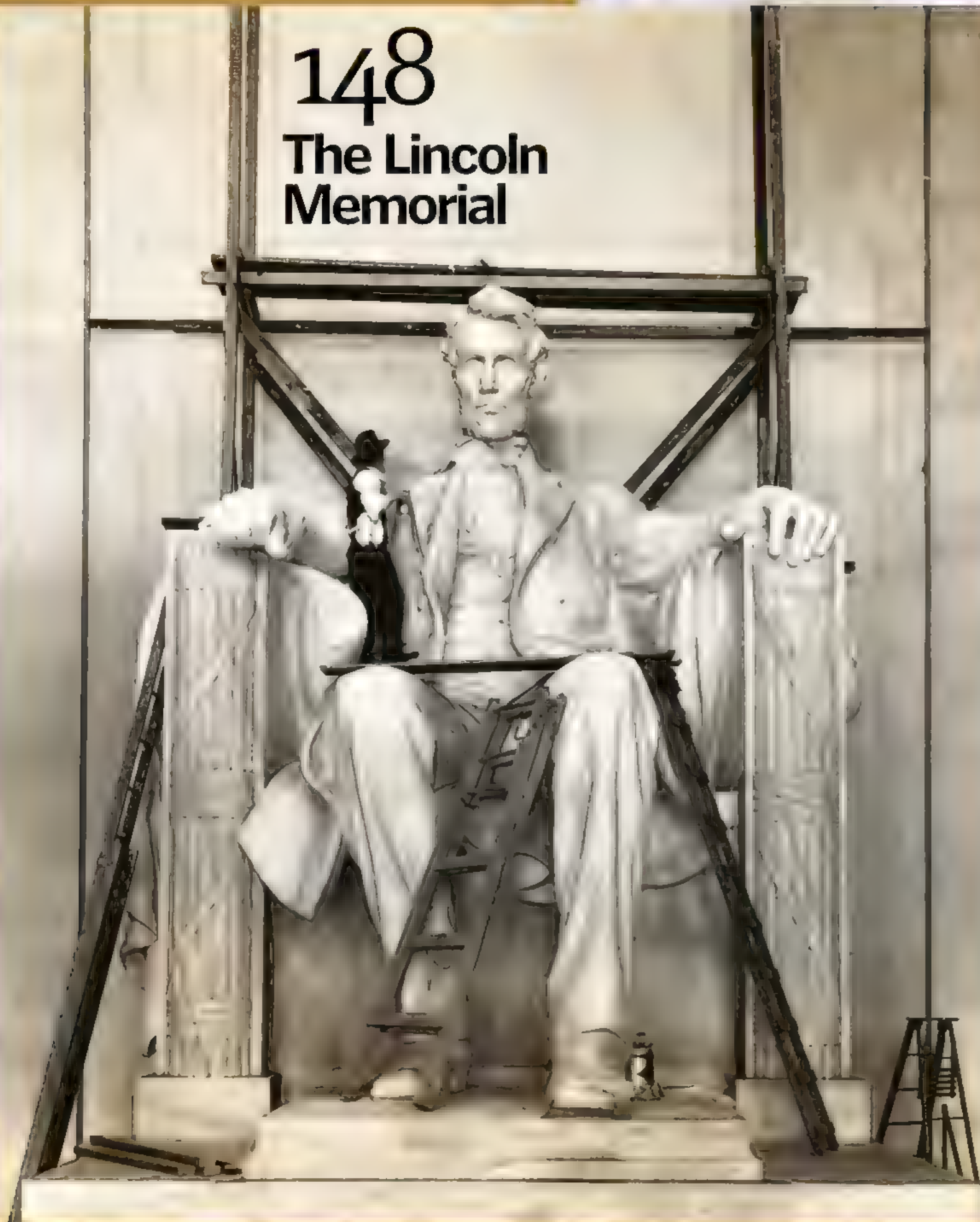
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Building Nazi Germany's famous armoured vehicle

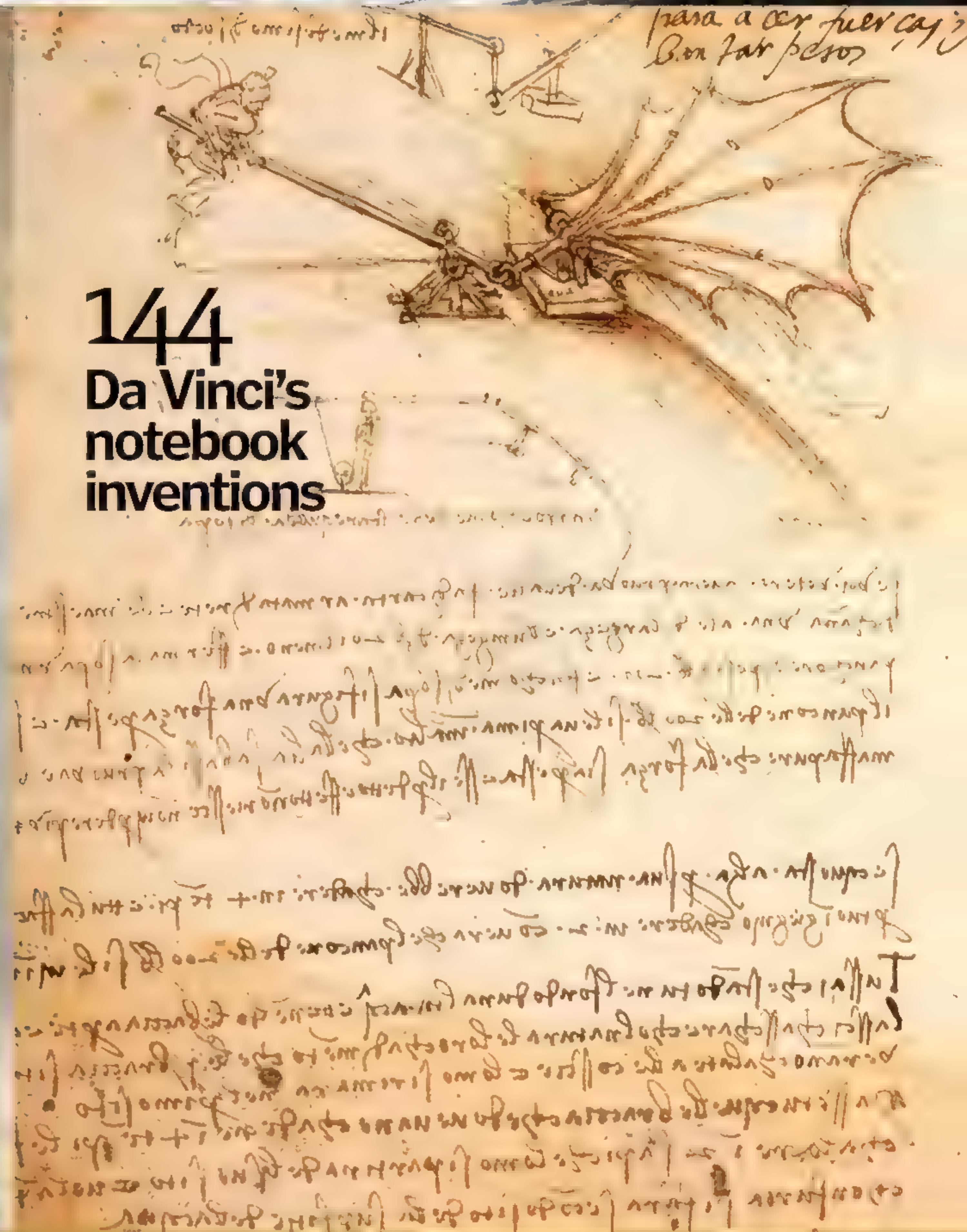


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IN

**The incredible ways nature has preserved
prehistoric humans and beasts for us to find today**

Words by **Amy Grisdale**

TIME

Borremose Man

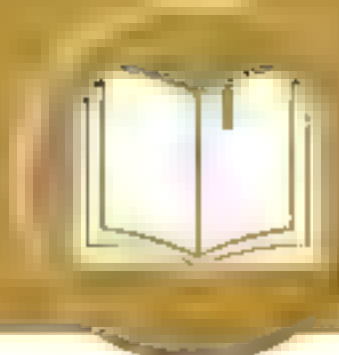
This body, dating from around 8400 BCE, was found preserved in a peat bog in Denmark in 1946

Carcasses trapped in tar pits attracted carnivores, who also got stuck in the sticky substance



The Earth has experienced monumental changes since it was formed some 4.5 billion years ago. It has undergone alternating phases of cooling and warming, and this swinging between extremes of temperature dramatically changed the ecosystem. It brought about mass extinctions and the chance for new species to evolve in their place. The animals that ceased to exist left impressions, from partial footprints to intact fossilised skeletons. In some circumstances, however, animals of the past found their way into environments that preserved their entire bodies while the rest of the species rotted away.

One excellent method of animal preservation is freezing. Cold weather grinds the speed of organic decomposition to a halt by preventing the growth of bacteria that would otherwise feed on the decaying flesh. Temperatures were five to 22 degrees Celsius colder than today's climate in the most recent ice age. Animals were well insulated with thick hair, such as the great woolly mammoth, or took shelter from the cold



Tusk hunters are always on the trail of precious prehistoric ivory



Ice is such an effective preservative that this prehistoric animal, a baby mammoth, looks like it's sleeping

like cave lions. Now most of the world has defrosted, but there are still areas that remain frozen, such as parts of Russia and Asia. Animals that lived and died in this bygone era have since been plucked from permafrost (a permanently frozen layer in the ground) with their bodies intact. A steppe bison that lived 36,000 years ago was uncovered in pristine condition in 1979. Its rear end still bore the claw and tooth marks from the Ice Age lion that killed it.

Specimens that have survived thousands of years often became trapped somehow before a sudden plummet in temperature. The presence of food in the stomachs of Ice Age animals indicates that their bodies were frozen rapidly, preventing decay.

A large proportion of frozen remains are unearthed by miners on the hunt for precious metals. Scientists are invited to remove and study the remains. They are then able to draw conclusions about how the animal lived day to day and what may have led to its extinction. Scrutiny of a woolly rhino found by gold miners in northern Russia in 2007 convinced researchers that the species died out because its legs were too short to move efficiently through deep snow.

"Lack of oxygen, low temperature and acidic water worked together to 'pickle' animal remains"

In the absence of ice, nature has other ways to preserve body tissue. An extremely important factor in preventing decomposition is separation from oxygen. Europe's peat bogs have a magical combination of a lack of oxygen, low temperature and acidic water, which works to 'pickle' the remains of any animal that meets its end in the mud. Over time, layers of moss form on the bog's surface and release chemicals that halt bacterial growth.

Some of the most famous remnants of the past uncovered in these bogs are almost immaculately preserved human remains, along with a plethora of bizarre ancient artefacts that have been recovered in recent years. Huge hunks of an edible waxy substance are sometimes found with these 'peat-bog men' that are thought to be made of dairy or meat. This

Tollund Man

A man was discovered in a bog near the Danish town of Tollund in such good condition he was initially believed to be a recent murder victim. The body had been lying in peat for some 2,300 years, still dressed in primitive clothing. He appeared to have been brutally murdered, but the experts discovered upon being dried, that his body may have been ancient grounds of burial or even ritual sacrifice.

'Tollund Man' was found with a braided leather cord wrapped tightly around his neck, and it's unclear whether he was hanged or strangled. The absence of trees across stretches of bog may have made people feel a connection to the heavens, and therefore made it a place of religious significance.



Tollund Man, a well-preserved ancient human body found in a peat bog

Bog embalming

Chemicals in Europe's bog waters are a perfect mix for preservation

No air

At depths of 30-50cm there is no oxygen left in the acidic soil. Bacteria cannot break the body down.

Raised bed

Elevated bogs contain the least oxygen but the most acid. These are the best at keeping a body fresh.

Sphagnan

Decaying moss releases a carbohydrate called sphagnan. This polymer extracts calcium from the bones, leaving the body soft and squishy.

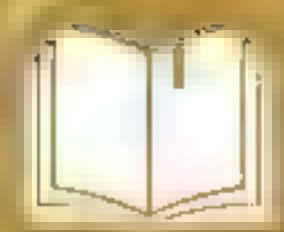
Under pressure

The weight of the water forces the peat soil to pack together tightly and nestle closely around the person.

The Tollund Man was killed with this 'leather rope', and his hat is made of skin

What was once sticky liquid tar now crumbles into easy-to-handle portions





Types of fossilisation

There are many ways animals and plants can be preserved or altered by the environment

Asphalt

Crude oil seeps out of the ground, slowly forming pools on the surface. The oil becomes more viscous and sticky, trapping animals that come into contact with it. Bones that have soaked in tar are stained a tan colour but otherwise are preserved without being affected by the environment.

Ash

Clouds of volcanic ash bury remains of living beings without crushing or burning them, causing less damage. The remains of the city of Pompeii sat under a heap of ash for 1,669 years, and the people who had been buried by the ash were preserved with remarkably little alteration.

Ice

Ice is an amazing tool for preservation. No parts of the body are replaced when frozen. A normal human body can decompose in as little as eight years if it is buried in soil, whereas corpses are known to have lasted for 5,000 years or longer when they have been buried in ice.

Carbonisation

The carbon in a soft-bodied animal creates an impression in sedimentary rock while the rest breaks down. A detailed carbon stamp remains on the surface, to be discovered later on. The majority of fossilised feathers are preserved as carbonised traces.

Sediment

Mud sitting at the bottom of a lake or a river envelops the carcasses of fish and invertebrates. It can accumulate and bury a dead animal very quickly, denying it oxygen and preserving the creature's flesh. Many millions of years can pass before it is once again exposed to the surface.

Amber

Tree resin solidifies as amber, and animals can get stuck inside – just like the mosquitoes in *Jurassic Park*. Insect exoskeletons, made of the protein chitin, emerge almost unchanged. Unfortunately, however, the inner soft tissue is not preserved.

Peat bog

Around 100 bodies have been found preserved in peat bogs, a quarter of which are considered to be in exceptional condition. The remaining 75 that have been found are skeletons. They are from northern Europe, especially Ireland, the UK, Denmark, Germany and the Netherlands.

Petrification

This is the process through which organic material is slowly replaced by minerals. The remains are completely altered by this process, and the fossils that are produced are really stony replicas of the organic original.

'bog butter' may well have been a treasured food product to slather on Bronze Age bread. It's possible that people of the past stored their butter in bogs to keep it cool and fresh, long before the days of refrigeration. It worked so well that this ancient spread is thought to still be edible – so long as the diner can ignore the smell.

Animals can get locked in a kind of time capsule by getting stuck in tar pits. In some parts of the world, springs of natural asphalt can seep up to the ground as thick crude oil. It accumulates and eventually forms a pool, the surface of which reacts with air to become thicker and stickier. We call these tar pits, and each one is a snapshot back in time. Prehistoric animals would get trapped and struggle to free themselves. The resulting commotion would

"Prehistoric animals would get stuck in the tar and struggle to free themselves"



The La Brea tar pit contains thousands of examples of preserved prehistoric creatures

then attract predators, some of which would be lost in the tar themselves. Thousands of years later, the solidified tar began to be mined as asphalt, and the treasures within came to light.

La Brea is a world-renowned tar pit in Los Angeles, California. It trapped creatures for over 30,000 years, and new discoveries are still being made to this day. The site has been under excavation since 1913, and over 3.5 million specimens have been found so far. More than 600 species of animals and plants have been identified from these remains, but most discoveries were bones of large animals. 90 per cent were carnivores like American lions and dire wolves. 4,000 dire wolves have been retrieved from the tar, and some 400 of their skulls are on display at the George C. Page Museum that stands on the excavation site.

Humans have learned so much from these pockets of prehistory. We have pieced together the events of evolution and have a detailed understanding of how we reached today. Chunks are missing, but areas that have preserved the past are helping us fill in the blanks.



Peat bogs, unremarkable at first glance, contain incredible pieces of history

How tar preserves prehistoric animals

Low-grade crude oil seeps out of the ground, encountering air for the very first time. Contact with oxygen causes small and simple hydrocarbon chains to oxidize or evaporate. As the lighter fractions of oil disappear, the remainder becomes 'gummy' and is less likely to evaporate. The tar begins to harden when it touches the cool air but remains viscous enough for a heavy animal to sink in.

Dust, leaves or even water can permeate the tar's surface, making it easy for a wandering roachdog to find of prehistoric elephants to stray into a natural vat of tar. It calls out to other members of its species for help, inadvertently alerting wolves and big cats to its plight. Even if it dies of starvation or dehydration, it takes up to 20 weeks to sink. During this time, it is visited by hungry predators that are also at risk of getting stuck themselves.



The George C. Page Museum is the home of the La Brea Tar Pits & Museum

Five incredible ice mummies

These frozen prehistoric animals are remarkably well preserved and prove time can stand still

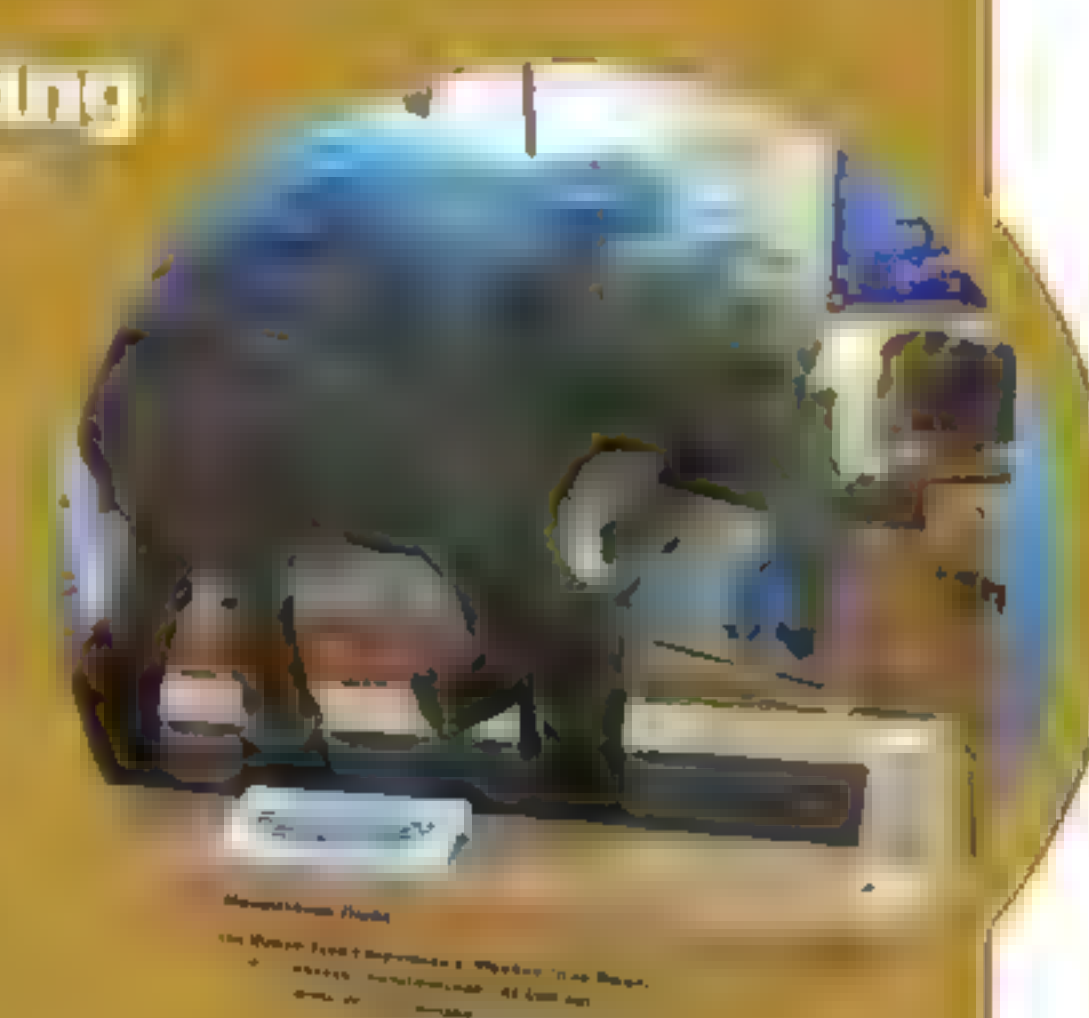
Sasha



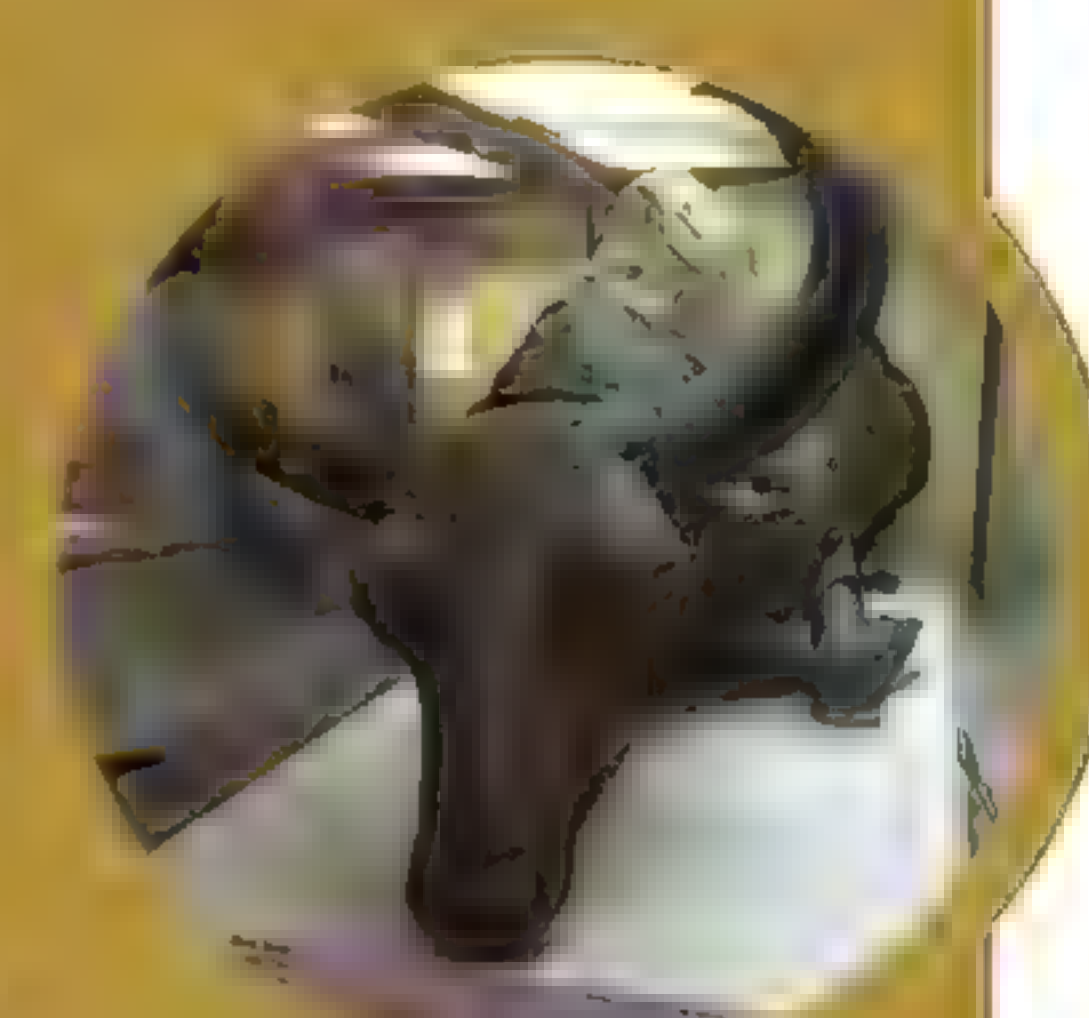
Lion or lynx



Death by drowning



Old but good



Frozen foal



Rebuilding Notre-Dame

This won't be the first time Paris' famous cathedral has been restored to its former glory

As the inferno engulfed the 850-year-old Gothic Notre-Dame cathedral on 15 April, the world was watching. The despair of Parisians was simulcast to millions of screens across the planet, with the tragedy trending on Twitter. But why is this medieval building a world-renowned landmark?

Notre-Dame (meaning 'Our Lady') is far more than a setting for holiday snaps and postcards. It's an icon of Gothic architecture that houses many amazing artworks and holy relics. While the French kings preferred to be crowned at Reims, Notre-Dame has been witness to many historic events.

Not that time has always been kind to the cathedral. During the French Revolution, rebels destroyed many of its statues, melted down its bells, and after a brief stint using it as a secular 'Temple of Reason', turned it into a warehouse.

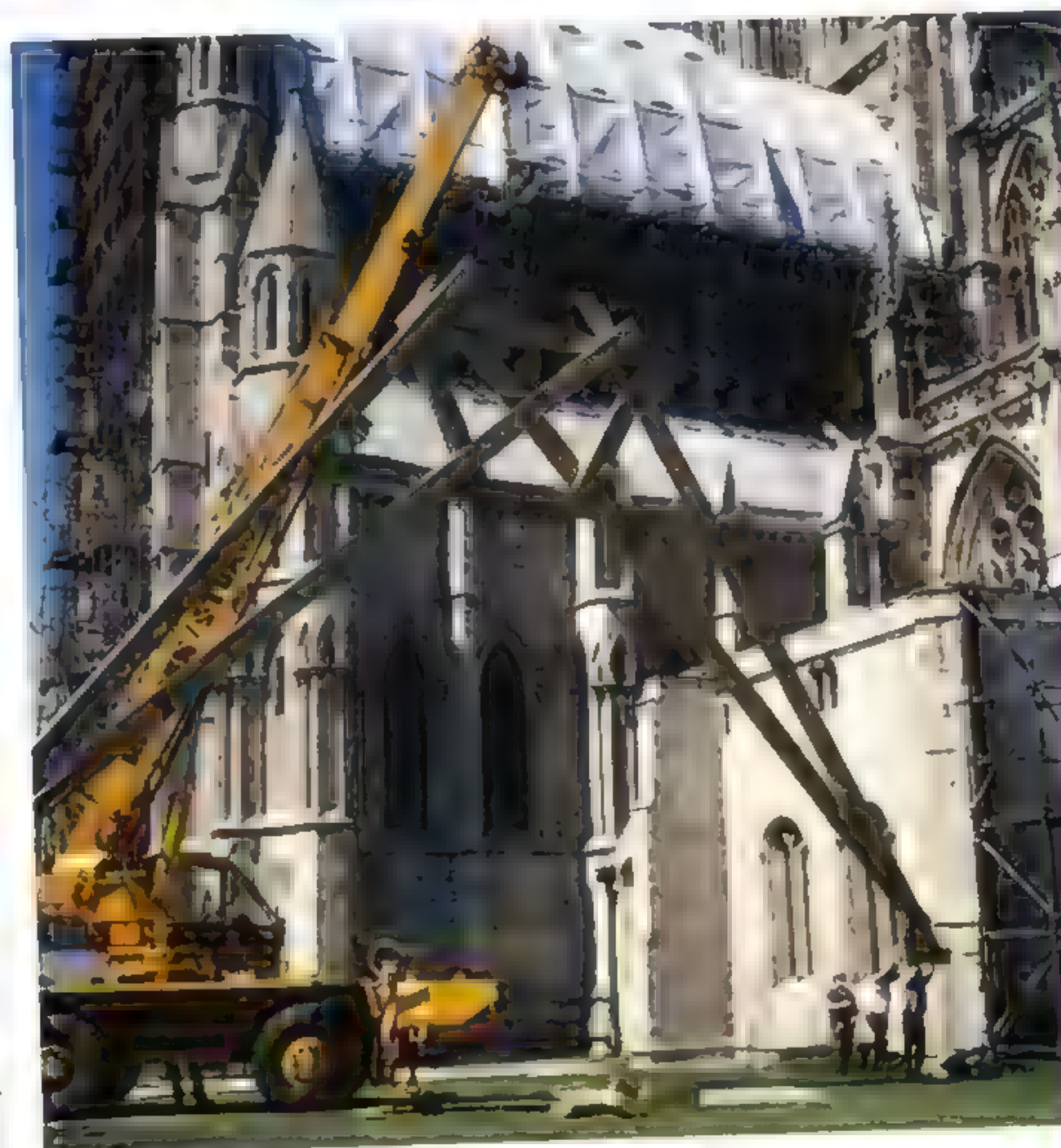
Later in the 19th century, when Paris's medieval ruins were being bulldozed, French author Victor Hugo argued they should be preserved. As well as publishing a pamphlet called *War on the Demolishers!*, he wrote *The Hunchback of Notre-Dame* – simply titled *Notre-Dame* in France.

The story of Quasimodo the cathedral bell-ringer captured the French public's imagination. This led to a nearly 20-year restoration of Notre-Dame, starting in 1844. While architect Eugène Viollet-le-Duc went to great pains to repair the damage, he was later criticised for making his own modifications and

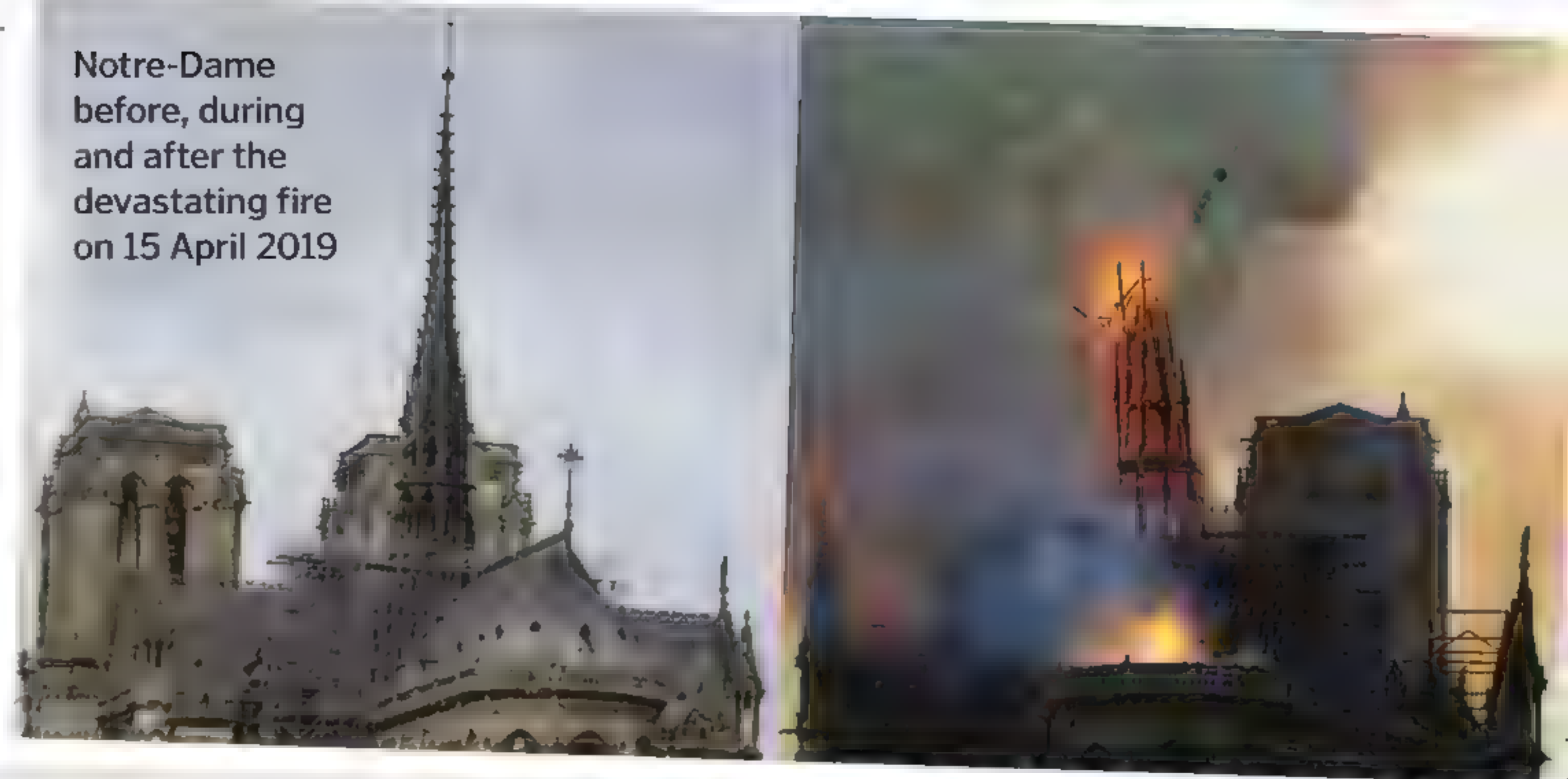
using more modern materials, such as concrete, to renovate the spire.

Despite further repairs in 1991, the cathedral was in trouble before this year's fire broke out. Ravaged by pollution, the Archdiocese of Paris believed it would cost over £141 million to restore Notre-Dame. While the fire caused even more damage, an international funding effort quickly began to help raise the cathedral from the ashes. Nearly £780 million was donated in the first 48 hours following the fire.

Craftspeople that helped repair York Minster, which was built 15 years after Notre-Dame, could help with the reconstruction



© A. Amy



Notre-Dame before, during and after the devastating fire on 15 April 2019

Notre-Dame 2.0

French President Emmanuel Macron has vowed to rebuild Notre-Dame in time for the Paris Olympics in 2024. But could this be possible? After a fire in 1984, it took four years to repair the damage at the 12th-century York Minster in England.

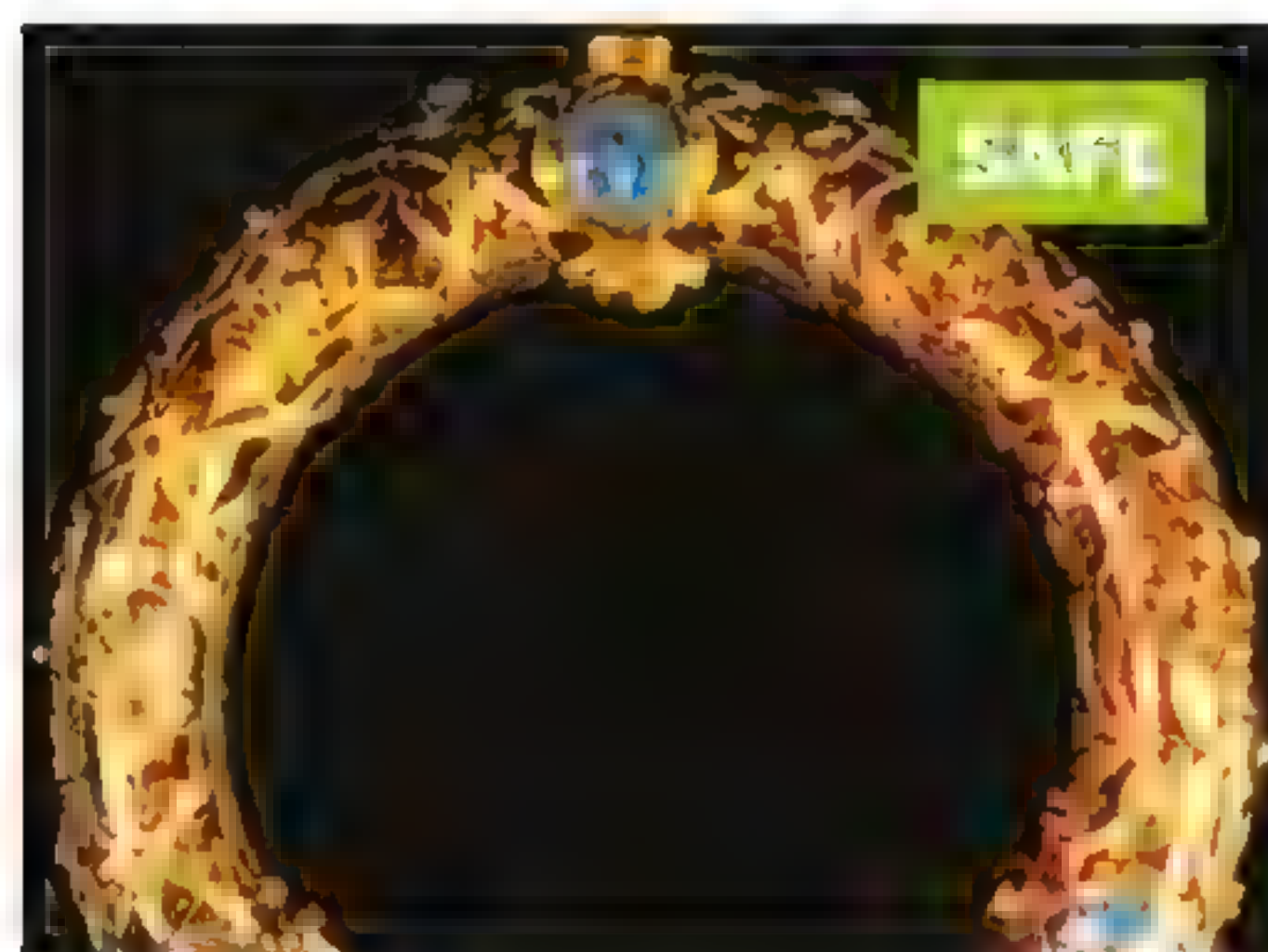
Of course, many of those who worked on York Minster could lend their expertise to Notre-Dame. New technology could also play a role. Laser scans of Notre-Dame from 2014 contain 3 billion data points. These could be used as a high-resolution 3D blueprint to help reconstruct the medieval structure.

A bigger problem may be finding medieval materials. 5,000 oak trees were used to build York Minster and timber used in the 12th century. Rebuilding similarly would require the removal of 100,000 tonnes of wood. Even if you could find the wood, it would be impossible to find the same quality of timber as in the 12th century. But with the modern technology of Paris, the restoration of Notre-Dame may now be a very real possibility.



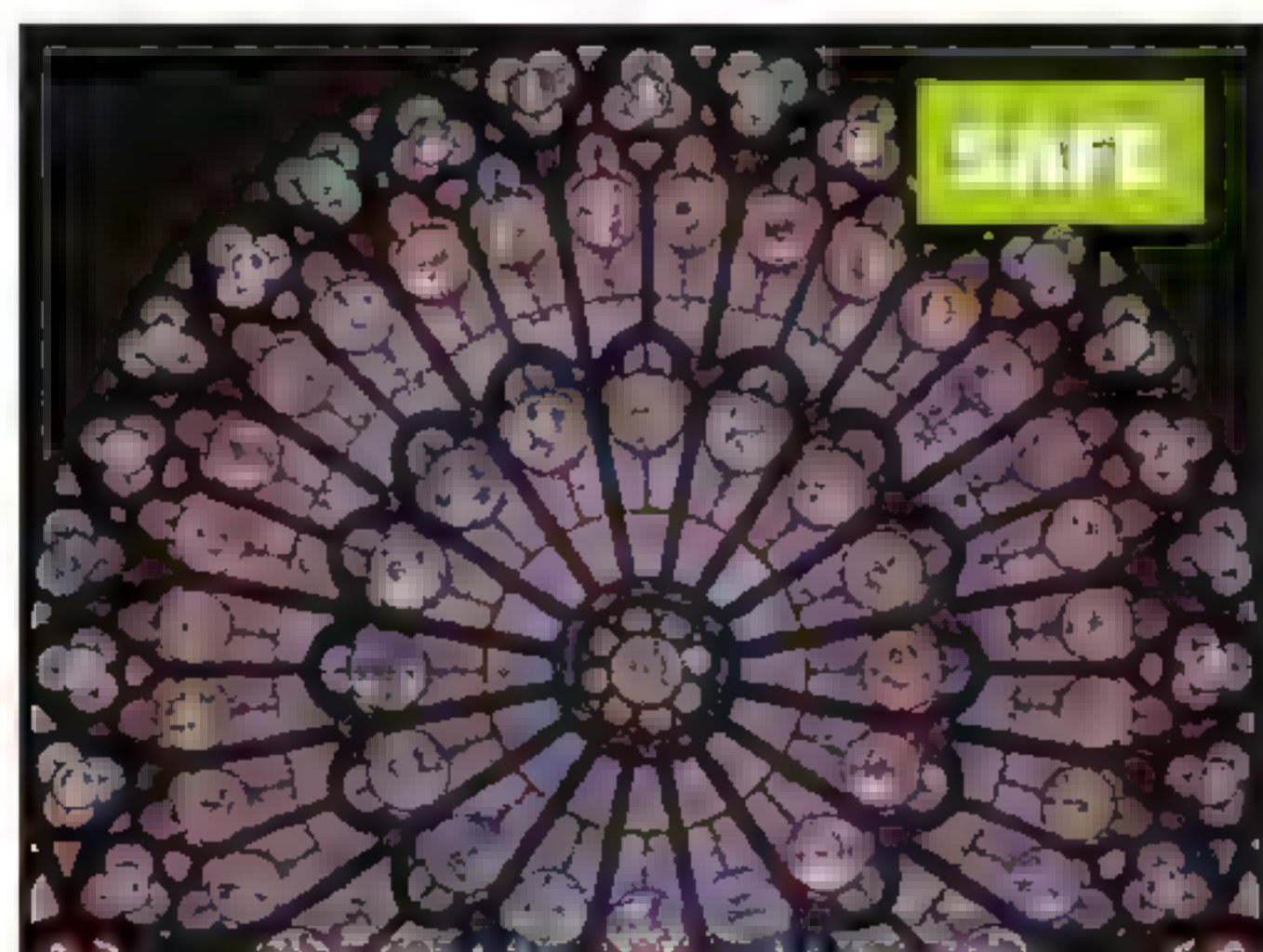
© The Ministry of Culture, Paris

The cathedral's treasure trove



Crown of Thorns

The most precious object in Notre-Dame's collection is believed to have been worn by Jesus Christ. Given to Louis IX in 1238, the thorns are preserved in a reliquary made of gold and crystal.



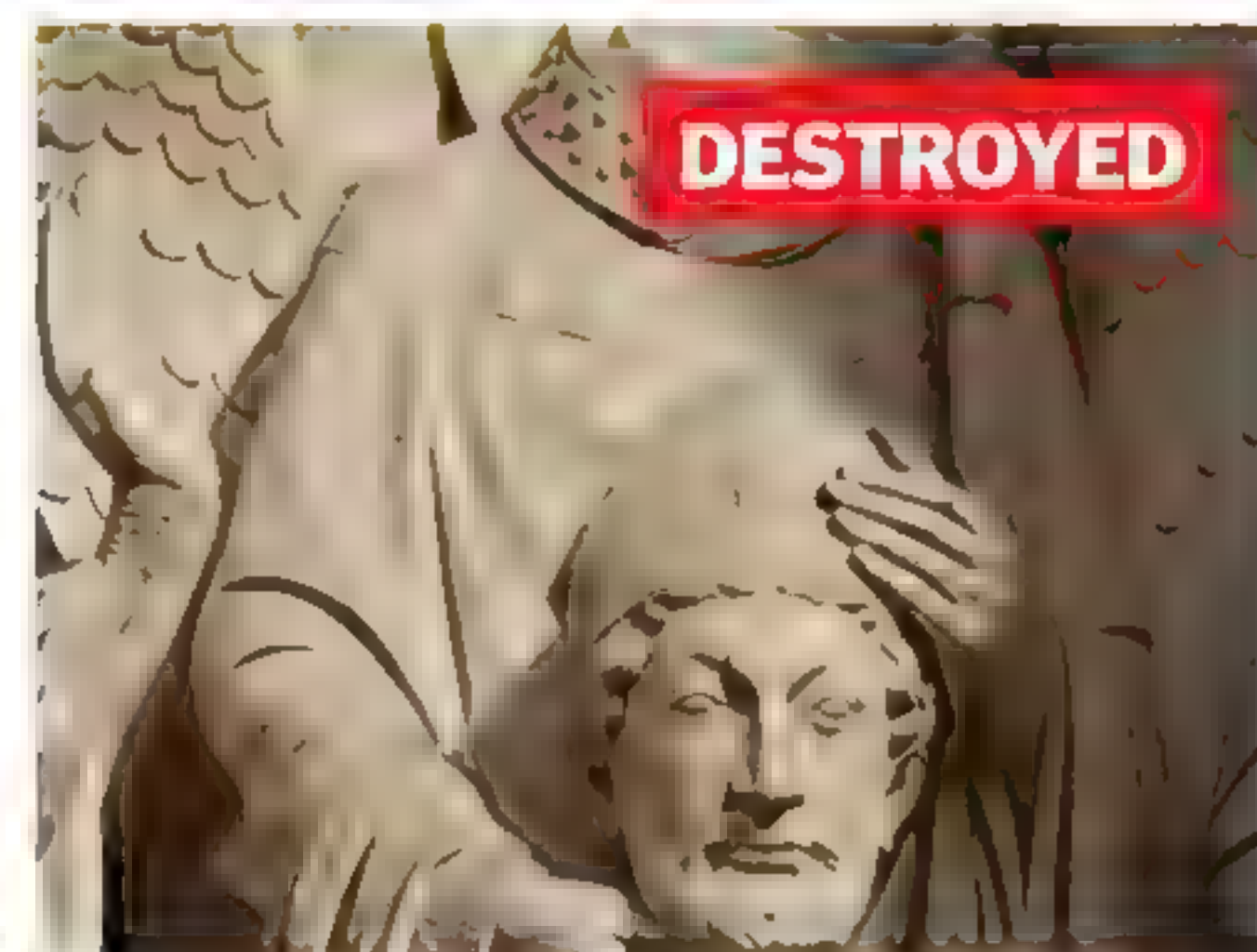
The rose windows

The cathedral's spectacular stained-glass rose windows are made up of petal-shaped panes, each depicting Bible scenes. The west window is the oldest, from 1125, while the south is a huge 12.9 metres in diameter.



The great organ

The largest organ in France, it was rebuilt in the 19th century, but some of its 8,000 pipes date from the 1200s. Organist Louis Vierne played 1,750 concerts before fulfilling his dream of dying at the instrument in 1937.



The relics of Saint Denis and Saint Geneviève

Bones, teeth and hair belonging to the patron saints of Paris were destroyed when the spire collapsed. An archbishop had placed them there in 1935 to protect the cathedral.



What was damaged?

The blaze came close to bringing down the medieval marvel

Gothic spire

Though the original medieval steeple was dismantled in the 1780s, the destruction of the 19th-century reproduction stunned onlookers.

Twin towers

While flames reached the iconic 68m-high bell towers on the western façade, fictional home of Quasimodo, firefighters successfully extinguished them. All ten bells survived.

How the fire spread

While it was feared the blaze could level the landmark, the flames were mostly confined to the rooftop. Though the exact cause is still being investigated, the fire began in the cathedral attic. This then ripped through the crisscross of 800-year-old wooden beams, which burned to ash. Possibly stoked by sawdust in the attic, the fire also caused the steeple to collapse. Notre-Dame's vaulted stone ceiling shielded the cathedral's interior – including its famous rose windows – from harm. But this masonry also stopped firefighters from being able to shoot water into the attic from the ground.

Bronze statues

Several days before the fire, the 16 bronze statues – including the 12 apostles – were airlifted to safety ahead of planned building work.

Irreplaceable roof

After the fire began in the attic, around two-thirds of the 800-year-old oak beams that made up the rooftop burned to ashes.

Flying buttresses

These icons of the east façade were an afterthought added in the 13th century, but may have helped support the structure as the inferno raged.

Rose windows

While it was feared the fire would melt the famous 13th-century stained-glass windows, all three survived.

Vaulted stone ceiling

While the carved ceiling likely shielded the interior from harm, it also stopped firefighters from being able to shoot water into the attic from the ground.

Saving grace

Despite the spire collapsing, the altar, pews and chancel windows in the eastern end of the cathedral remained intact.

Upper windows

While the rose windows survived, less famous frames nearer the rooftop were not so lucky, including one between the towers and another on the south side.

The rise, fall and resurrection of Notre-Dame

1163 FOUNDING FATHER

The cathedral's first stone is laid on Paris's Île de la Cité, with Pope Alexander III attending the ceremony.

1185 CALL TO ARMS

Heraclius, archbishop of Caesarea, calls for the Third Crusade from the still-unfinished cathedral.

1431 CROWNING ACHIEVEMENT

During the Hundred Years' War, ten-year-old Henry VI of England is also proclaimed ruler of France in Notre-Dame Cathedral.

1548 RELIGIOUS RIOTING

Rioting French Protestants – known as Huguenots – damage some of the statues in the Catholic cathedral.

1793 OFF WITH THEIR HEADS

Mobs loot the cathedral during the French Revolution and even decapitate 28 statues of biblical kings in a mock execution.

1804 ALL HAIL NAPOLEON

In a lavish ceremony at the cathedral, watched by a cheering crowd, Napoleon crowns himself emperor of the French.

1844 NOVEL COMEBACK

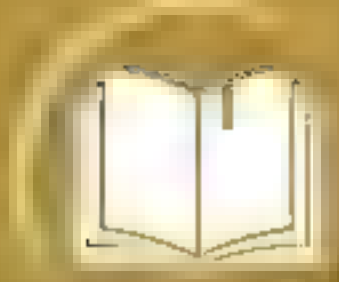
The popularity of Victor Hugo's *The Hunchback of Notre-Dame* prompts a major restoration of the cathedral.

1871 PARIS IS BURNING

During the Paris Commune insurrection, Notre-Dame is set alight, but it doesn't cause lasting damage.

1914 THE SKY IS FALLING

WWI sees the rise of aerial bombing, but Notre-Dame survives relatively unscathed – except for a hole in the roof.



Da Vinci's **AMAZING NOTEBOOK INVENTIONS**

**Flick through the pages of the original Renaissance
man's greatest inventions and scientific studies**

Words by **Scott Dutfield**

Born in 1452 in Tuscany, Leonardo da Vinci spent his life in the pursuit of knowledge and artistic expression. Now revered for his great works of art, such as the *Mona Lisa* and *Salvator Mundi*, da Vinci's scientific notes suggest his thinking was hundreds of years ahead of his time.

He filled countless notebooks during his career, each bursting with observations about the natural world, the human body and numerous mechanical inventions. One collection in particular, the *Codex Atlanticus*, spans 12 volumes and includes 1,750 drawings.

One of the main focuses in his engineering endeavours, the concept of putting a man in the sky, piqued his interest, and a string of flying machine designs followed. One of his drawings details the design for an 'aerial screw'. Appearing as the ancestor of the modern-day helicopter, this machine was designed to test the air's ability to compress and support human travel in the air. The aerial screw was one of

many flying machines conceived by da Vinci, including one that replicated the flapping wings of a bird, but none were made in his time.

Designing multiple other engineering concepts, including weapons, theatrical equipment and hydraulic machines, da Vinci's notes are an inspiration.

Da Vinci is also well known for the study of the human body – both outside and inside. Around the 1480s his attention turned to the study of human anatomy to better understand the subjects of his art. From the structure of a single hand to the entire circulatory system, da Vinci studied the body in its entirety. His anatomical studies mainly used animal subjects, though by the time of his death he had also performed 30 or so human dissections, mostly using executed criminals and unclaimed bodies.

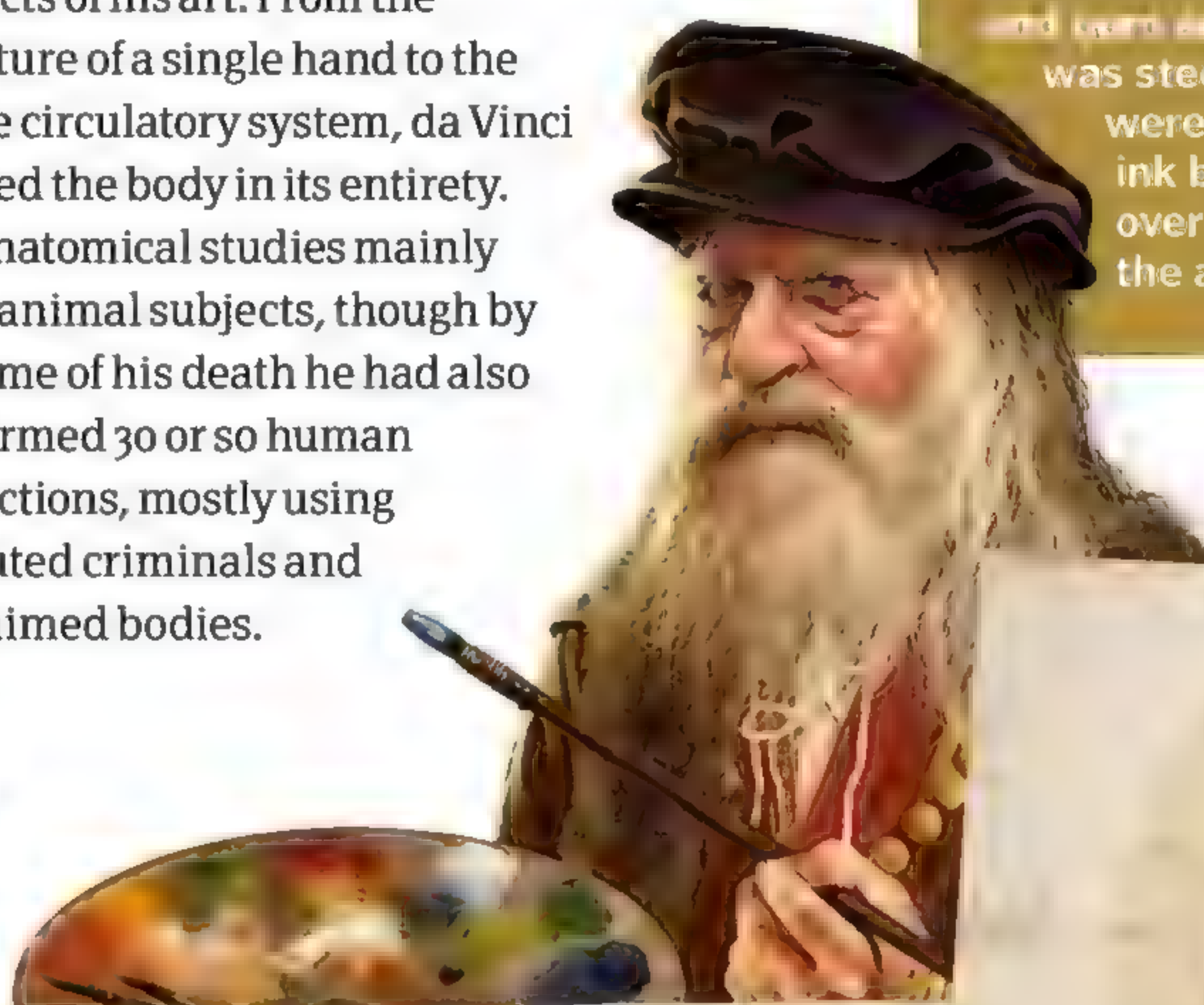
Ink innovation

Made from oak tree galls, iron sulphate and gum arabic, it's a wonder how these three ingredients ever found their way together to produce da Vinci's black ink. At a time when ink was commonly made using home recipes rather than being sold as a product, its manufacture was quite time-consuming. Crushed in a cloth, the oak galls were soaked in rainwater and boiled. The resulting liquid was then strained and combined with iron sulphate and gum arabic. This creation was then steeped until all the ingredients were completely dissolved. The final ink began as a pale violet grey, but over several days the exposure to the air turned the ink black.

In his notes, da Vinci mapped the city of Imola, Italy, after being named general architect and engineer to Cesare Borgia, c. 1502

Making a heart of glass

In order to study the inner workings of the human heart da Vinci created a glass model to test his theories



Gypsum mould

Having cut away the heart's muscular flesh, the freed wax cast was then used to create a mould made of gypsum (a kind of mineral).

Molten wax

Da Vinci poured molten wax into the heart's chambers to create an internal wax cast.

Glass filling

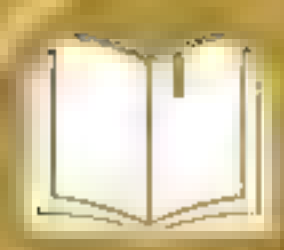
A thin coating of glass was blown into the gypsum mould to form a new transparent replica of the heart.

Water pump

Once the model was completed, da Vinci pumped water and grass seeds through it to explore how the chambers pump blood.

Ox heart

Believed to be similar to that of a human heart, da Vinci carried out a great deal of his studies on the organs of other species, such as the ox.



Seeing the invisible

Over time the work of da Vinci, like that of many other artists, has become vulnerable to damage from light, atmospheric or physical erosion. However, with the help of ultraviolet (UV) light previously unseen work can be brought back to life. This was the case with a set of hand drawings da Vinci had completed as studies for his painting *Adoration of the Magi*. Invisible to the naked eye, these seemingly blank pieces of paper revealed the illustrations when illuminated with UV light. This was due to the type of ink da Vinci used. Under UV light certain materials, such as paper, luminesce (glow). The luminescent ink, though faded, blocks the luminescence, revealing the hidden images on the page.

Seen in his surviving notes and anatomical drawings, da Vinci made waves with his near-accurate description of the human heart. Using his characteristic resourcefulness, da Vinci set to work creating a glass heart from that of an ox. He then not only noted its appearance in detail but proceeded to put his theory of its function to the test.

By pumping water through the glass da Vinci deduced that there were vortices (a strong movement of blood) in the heart's chambers. This motion was responsible for the closure of the heart's valves after each pump of blood. Incredibly, it wasn't until the introduction of real-time MRI scanners that da Vinci's work was confirmed as accurate.

"Had he not done anything else in his career, had he not painted a single thing, this would have still marked him out as being one of the great figures of the Renaissance, certainly one of the greatest scientists, both in the depth and the range of his work on human anatomy," explained Martin Clayton, head of prints and drawings for Royal Collection Trust at Windsor Castle and a specialist in the drawings of Leonardo da Vinci.

Da Vinci's scientific studies, however, didn't always bear the fruit of scientific discovery, and the results of many of his endeavours often left him scratching his brilliant head.

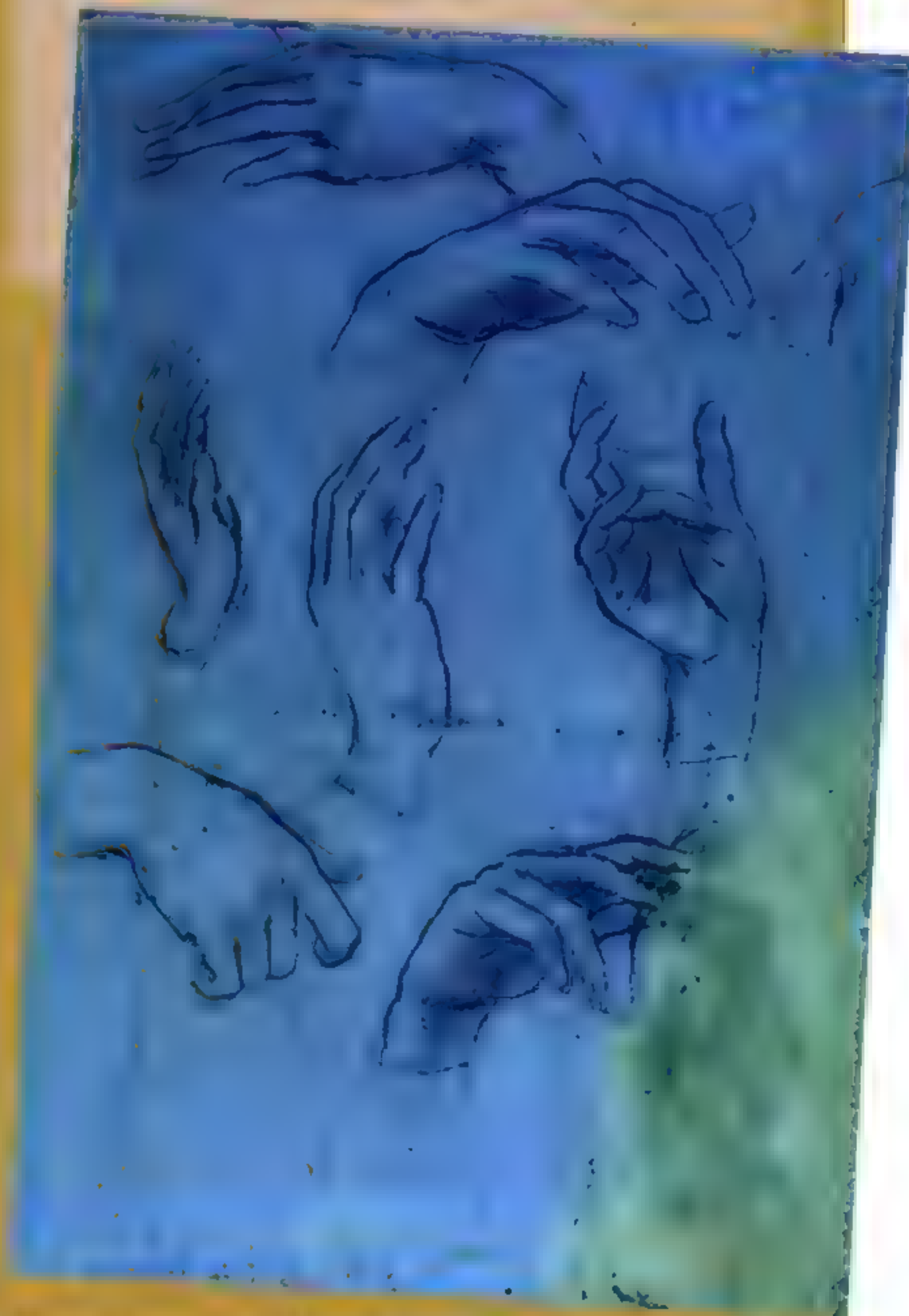
In the later years of his career, da Vinci's notes turned to the movement of water. He thought that by observing water he could understand the basis of force and movement. His extensive notes on the subject of water worked to codify its movement and interactions with the air. He drew the eddies and the circular motions that occur when water pours into a pool, for example.

However, unlike his engineering and anatomical work, this study highlighted some of the fundamental difficulties da Vinci faced.

"Leonardo as a scientist finds it very difficult to move from the specific to the general," notes Martin Clayton.

"His scientific observations tend to restate endless specific examples rather than overarching principles. That is one of his downfalls as a scientist."

Da Vinci drew a human embryo within a human uterus with a cow's placenta, believing that mammals shared a common anatomy, c. 1511



Da Vinci's inventions through the years

In studies of water, da Vinci noted its movements in relation to physical law, c. 1510-12

Drawn by his pupil, Francesco Melzi, this is one of the only remaining portraits of Leonardo da Vinci, c. 1515-18

Wing structure

Designed to have an iron frame, wooden ribs and linen covering, this helical structure was supported by a central wooden mast and reinforced with tension lines.

Leonardo's aerial screw

One of da Vinci's many inventions, the aerial screw was designed to fly like a modern-day helicopter

Pilot deck

At the base of the aerial screw was a platform or 'pilot desk' split in two - one stationary base and another that rotated with the spiral wing.

Flying

As the pilots turned the operating tiller in the centre of the structure, the spinning spiral wing was hypothesised to bore its way into the air like a screw into wood.

1482-1485

Wall defence

Through a series of levers and beams, da Vinci devises a system to push the ladders of opposing forces away from defensive walls.

1485

Armoured car

This vehicle is protected by a giant shield, with a series of cannons mounted around the circumference. Fitting a horse inside to drive it would prove impossible.

1487-1489

Flapping wing

To test out his theories of human flight, da Vinci sketches a flapping wing apparatus and a counterweight to see how moving the wing could lift weight.

1487-1489

Swing bridge

Da Vinci notes down three studies of bridges, including a swing bridge and a floating bridge, though the designs never leave the pages of his notebook.

1504

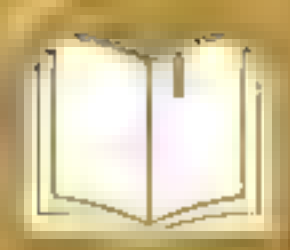
Bombards

Intended for presentation to a patron and not part of his unique studies, these gunpowder-fuelled exploding cannonballs are designed to release deadly wedge-shaped iron pieces.

1513-1514

Dredger

During the last few years of his illustrious life, Leonardo da Vinci designs a man-powered dredger that can scoop mud from water systems in order to prevent overflowing.



The pillars on which Lincoln's hands rest are fasces, wooden bundles associated with power

Approximately 40% of the Lincoln Memorial is located underground



The Lincoln Memorial

Why was the 16th president honoured with a memorial that looks like a Greek temple?

Strength, wisdom, fortitude – for many, United States president Abraham Lincoln embodied all those qualities, so when he was brutally assassinated in 1865, plans for a memorial in his honour began immediately. However, years of disagreement over the project meant that construction didn't commence for nearly 50 years.

The finished temple-like building stands at 30 metres (98 feet) tall, a dominating feature of the nation's capital, Washington, DC. Architect Henry Bacon drew inspiration for his design from the Parthenon in Athens. He felt it was fitting to honour a man who defended democracy with a structure from the very birthplace of democracy. And the symbolism doesn't end there. The building's 36 columns represent the states of the Union at the time of the president's death, with the entire memorial constructed from stones from different parts of the United States to convey the importance of the Union to Lincoln.

The enormous statue of the man himself was carved from Georgia marble and took four years to complete. It was designed by Daniel Chester French, who studied photographs and

eyewitness accounts from the Civil War to get the facial expression just right. The statue sits in the central hall, which is separated from two other chambers by rows of columns. More than just decorative, these provide structural support for the ceiling.

Great care had to be taken to ensure the walls and foundations were strengthened, due to the marshy terrain. The ground had to be drained and filled, and 122 solid concrete piers (cylindrical columns) with steel reinforcements were rooted into the bedrock. Above that is a second series of piers, joined together with concrete arches to form the memorial's floor. More supports were added when the Lincoln statue doubled in size to 5.79 metres (19 feet).

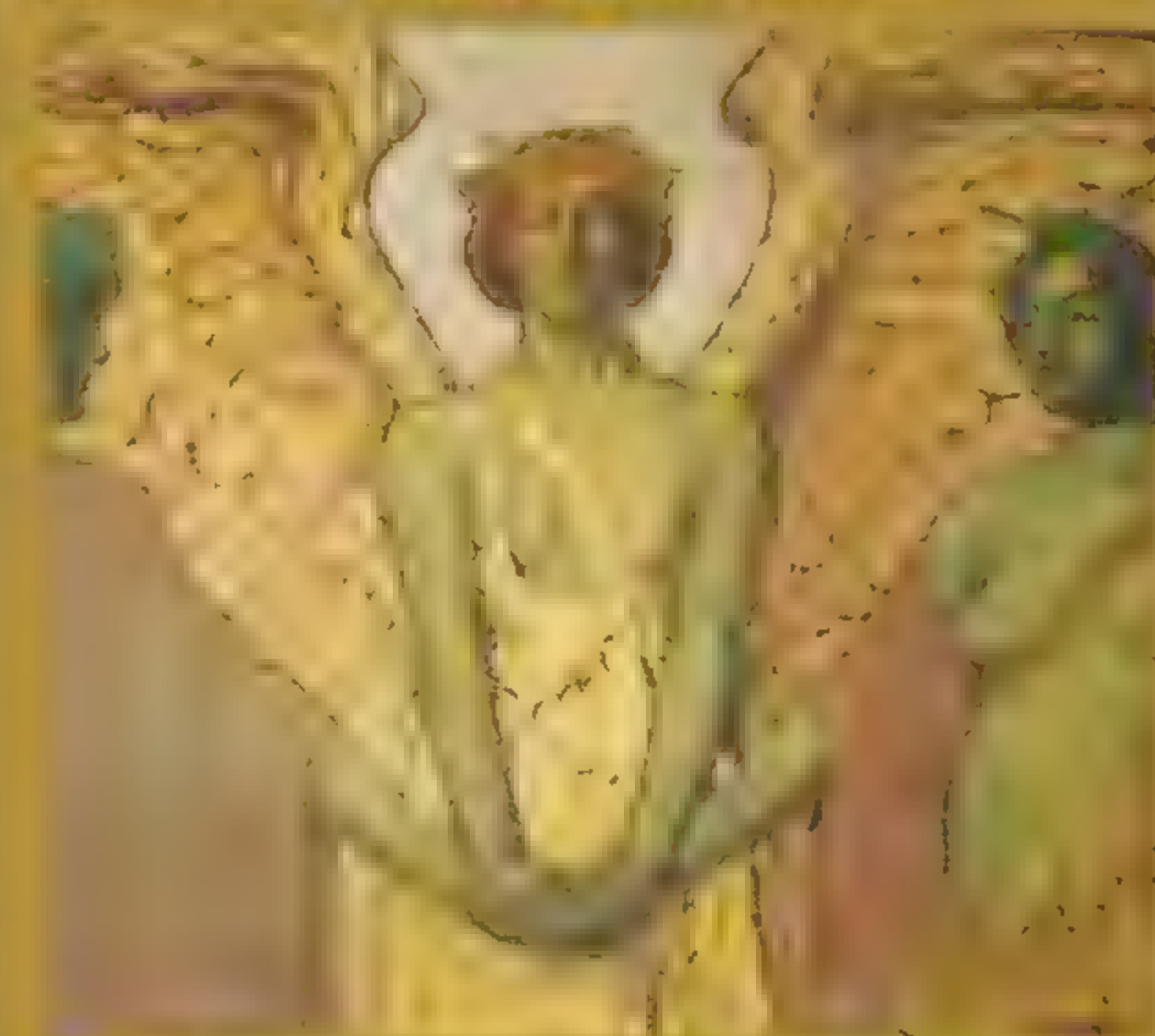
In 1922 the memorial opened to the public as a shrine, a museum and a place of pilgrimage for millions of visitors.

"The 36 columns represent the states of the Union at the time of the president's death"

Murals and meanings

Behind the larger-than-life Lincoln statue are the words, "In this temple, as in the hearts of the people for whom he saved the Union, the memory of Abraham Lincoln is preserved forever." Written by New York Herald Tribune art critic Royal Enghart, the inscription stands on the purpose of this memorial structure. This is accompanied by descriptions of two of the president's most famous speeches and the north and south walls.

The Gettysburg Address was delivered during the American Civil War in 1863 and stressed the president's determination to reunite the nation. The other is the Second Inaugural Address – delivered in 1865 just before the end of the Civil War – which asked people of the Union to stop fighting, forgive, and work for all. Above each inscription is a large mural painted by Jules Guerin. They depict the Angel of Truth releasing doves and joining the hands of two figures in unity, respectively. The paint was mixed with kerosene and was to protect them from the temperatures and moisture, preserving them for years to come.



Detail of the mural on the north wall of the Lincoln Memorial



The Lincoln Memorial is at the western end of the National Mall in Washington, DC



The ceiling tiles were made from Alabama marble and soaked in paraffin to turn them almost translucent

Tiger tank anatomy

Nazi Germany's ultimate heavy panzer was designed to strike a decisive blow for the Third Reich

The Panzerkampfwagen VI, more commonly known as the Tiger I, was developed in the early 1940s with the aim of creating an unstoppable armoured killing machine for the German military. Two rival engineering companies, Porsche and Henschel, were approached to produce prototypes for the tank, meeting specifications such as weight, cost and weapon capability. Henschel's design was eventually selected and rushed onto the production line in order to quickly deploy on the Eastern Front, joining Hitler's ongoing invasion of the Soviet Union.

It took five crewmembers to operate the Tiger: a driver, gunner, loader, commander and radio operator. The tank's main weapon was a 88mm gun, which was originally designed as an anti-aircraft artillery piece. At the time of the Tiger's first deployment, this huge cannon was capable of penetrating any enemy armour from long range. Years after its first deployment, during the Battle of Normandy in 1944, this enabled Tiger crews to ambush Allied formations from a distance, unleashing devastating fire before their enemy had a chance to respond.

The Tiger's armour was 100mm thick at the front – strong enough to stop or deflect nearly any Allied return fire. Battlefield accounts of Tigers in combat report round after round of enemy fire failing to penetrate its formidable shell. Unlike another prolific German tank, the Panther V, the steel plate protection of early Tigers was not angled, which provided less protection. This angled design feature was later added to the King Tiger, which was completed in the final months of the war – too late to prevent the defeat of Nazi Germany.

Despite its fearsome reputation on the battlefield, the Allies were eventually able to counter the Tiger I's capabilities, outnumbering, outmanoeuvring and eventually outgunning the once-dominant machine. Today, the Tiger remains among the most iconic vehicles of WWII and a milestone in the history of armoured warfare.



A still from a Nazi propaganda film showing a formation of Tiger II tanks

MG 34

To the right of the driver, the radio operator would also use the 7.92mm machine-gun, mounted in the front of the hull.

Turret

The loader, gunner and tank commander would all occupy the turret, which could also be armed with an additional MG 34.

Armour

Armour plating was over 100mm thick at the front, but the hull was much weaker at the sides and rear.

Driver

The driver's seat was at the front left, with a forward-facing viewing hatch that could be closed during combat.

88mm gun

Originally designed for anti-aircraft purposes, the Tiger's huge cannon had a devastating range and armour-piercing capability.

A paper Tiger?

Although the size and weight of the Tiger posed a formidable threat on the battlefield, the tank never struck the decisive blow so dramatically desired by the German high command. Among the major challenges to the Tiger tank's success were its high fuel consumption, its mechanical complexity, its high maintenance requirements, and its high cost. By the time the Tiger was deployed, many of its potential advantages had been offset by these drawbacks.

In addition, the tank's large and complex turret, its high fuel consumption, and its high maintenance requirements made it difficult to produce. High fuel consumption was also a major drawback to the tank's effectiveness, meaning it only had an off-road range of up to 100 kilometres.



A photograph of a Tiger tank in a field.

Killing machine

Precision engineering made this German heavy tank a lethal adversary in its day

Engine

The Tiger I was fitted with a re-engineered 700hp engine fed by four fuel tanks capable of carrying 534L.

Wheels

Early models featured 48 steel wheels with rubber tyres (24 each side) while later variants were fitted with 32 all-steel wheels.

Tracks

The Tiger's tracks were wider than average to provide extra traction and were fitted with a suspension system to withstand rough terrain.

Other big cats

Although the Tiger I was the most numerous and notable of Nazi Germany's heavy tanks, several other versions were also developed to tackle specific combat scenarios. The Panzerflieger Tiger, or 'Elefant', was a tank destroyer based on the chassis of a Tiger but designed to hunt down enemy vehicles. The Elefant featured a fixed turret, meaning that it could not rotate to adjust its aim, and its 88mm gun therefore straddled and bisected the front of the chassis, resembling an elephant's trunk.

Another short-lived Tiger variant was the Sturm Tiger, an assault tank that was developed with one job in mind – to demolish anything and everything that stood in its way. Armed with a massive 180mm cannon, the Sturm Tiger fired



The Elefant featured a fixed 88mm cannon, bisecting the front of the chassis.

rocket-propelled shells that could be used to raze enemy positions by igniting multiple buildings. Only 19 Sturm Tigers were ever developed, making them another curious but small footnote in the history of the Tiger tank.

Evolution of German armour



PANZER I

1934

Small, nimble and lightly armed with two machine-guns, these tanks were manned by just two crew members.



PANZER IV

1937

Fitted with a 75mm turret cannon, this was the most numerous German tank during WWII, with over 8,000 produced.



TIGER I

1942

With a huge 88mm gun, the Tiger I favoured firepower over the greater manoeuvrability of the Panther.



PANZER V PANTHER

1943

Developed to tip the balance on the Eastern Front, its sloped armour plating increased its effectiveness against horizontal ballistics.



TIGER II

1944

The King Tiger combined the effective sloped armour of the Panther with an improved 88mm cannon.



PANZER VIII 'TIGER MAUS'

1944-5

The 'super heavy' Tiger II successor would have carried a 128mm cannon with 250mm sloped armour. The project was never completed.



SPECIAL



WHAT THE

DINOS



REALLY
LOOKED
LIKE





SAURUS

HOW INCREDIBLE NEW DISCOVERIES ARE BRINGING THESE PREHISTORIC BEASTS BACK TO LIFE

Written by Amy Grisdale

The reign of the dinosaurs began just after the biggest mass extinction Earth has ever seen. 70 per cent of land animals and 96 per cent of marine species were obliterated in a mysterious cataclysmic event around 250 million years ago. Evidence shows this Permian-period extinction happened in phases. It could have been a series of giant meteor impacts or an increase in volcanic activity that caused fires and explosions worldwide. It's also possible a sudden surge of methane from the ocean floor brought about abrupt climate change.





The most complete T. rex skeleton we've found is named Sue. It is over 90 per cent complete

© Chase Elliott Clark

Whatever happened, it appears to have been quick. The surviving animals entered a new geological era, during which they would go on to dominate the planet. Vegetation exploded in the absence of so many animals, and after a period of 10 million years conditions were just right for new species to thrive. A group of reptiles called archosaurs took control and began to adapt to their new surroundings in the middle of the Triassic period. Dinosaurs of every shape and size roamed the Earth for the next 170 million years, from the crow-sized Microraptor to the blue-whale-sized Argentinosaurus. The last dinosaurs died out in the most recent mass extinction that paved the way for humans to evolve. Their fossilised remains lay buried for millions of years before humans even existed.

Dinosaur remains weren't recognised for what they truly were until 1824. Oxford University professor William Buckland studied bones that had been discovered some 150 years earlier by naturalist Robert Plot. While Plot was convinced they were remnants of a race of giant humans, Buckland knew they must have been from some kind of carnivorous lizard. He called his new discovery Megalosaurus – 'great lizard'.

"Dinosaurs of every shape and size roamed the Earth for the next 170 million years"

In the 19th century new discoveries were met with some scepticism. Amateur fossil collector Mary Anning found the first complete plesiosaur skeleton in 1824, but experts had their doubts. Georges Cuvier was famous for founding the study of vertebrate biology and gave his name to over 50 animal species that are still alive today. He voiced his concern that the find was a hoax. He was certain there were too many bones in the neck for the animal to hold it up and suspected the fossil was two species fused together.

The Geological Society agreed that something dubious was going on and called a meeting to



The remains of an Oviraptor were found near a nest (they were thought to eat eggs), but in this case it was actually defending its own clutch

© Hombredigital



Dinosaurs were killed by other dinosaurs, and survived injuries that would have been deadly to the average mammal

Prehistoric forensics

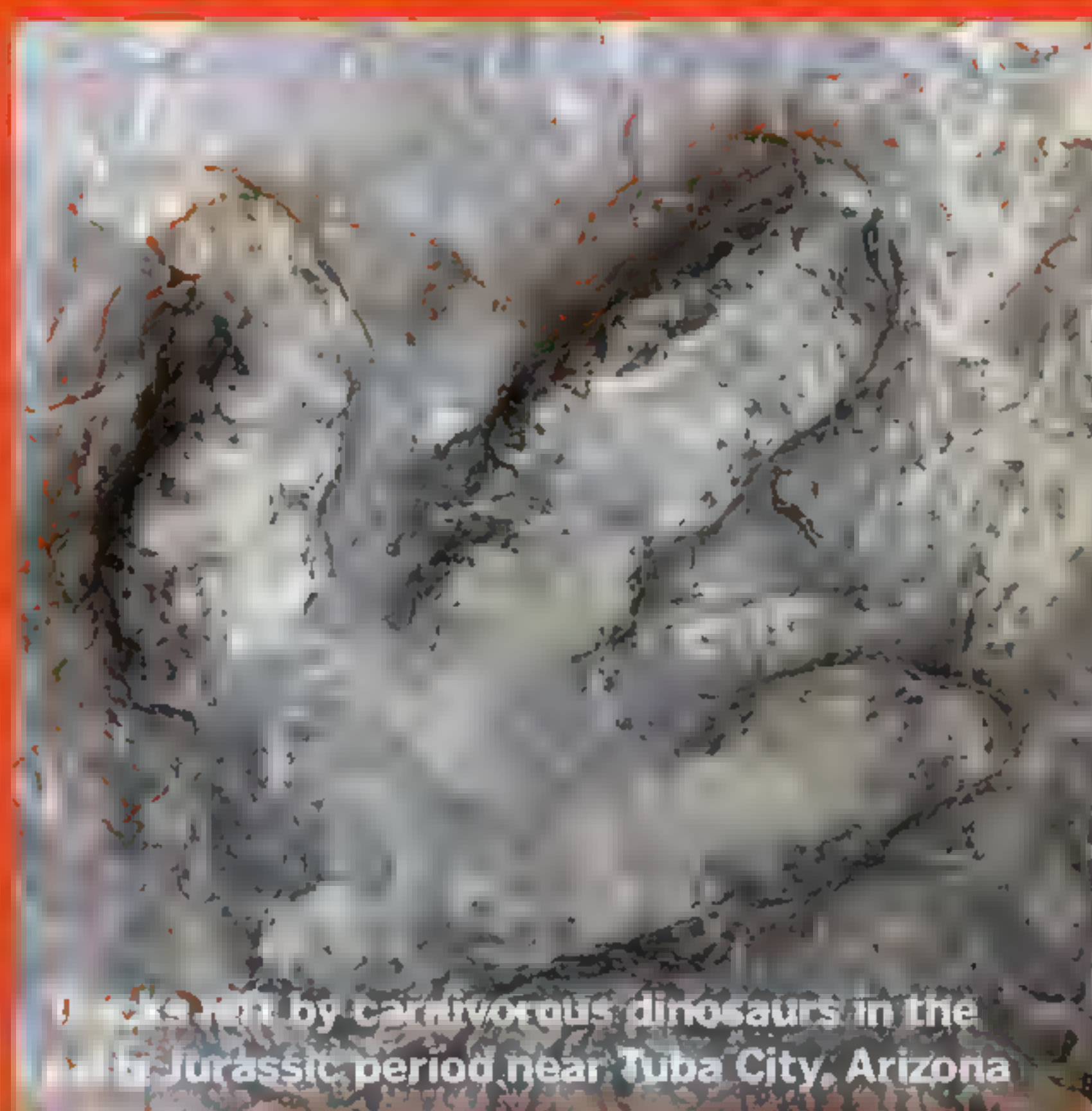
We can determine the cause of a dinosaur's death by examining bones, footprints, skin, teeth and eggs. Physical trauma could be fatal, such as damage inflicted by another animal. Fights must have been brutal. A fossil of the theropod *Allosaurus fragilis* found in Wyoming, US, in 1991 had 19 fractures. Another was uncovered five years later with 13 damaged bones literally from head to toe.

Bone diseases could cause death through deformities, tumours and infections. We can even recognise healed fractures and identify what species left tooth marks in fossils. Remains with a rough texture indicated the animal suffered a degenerative disease. A virus that originated among the dinosaurs may be responsible for hepatitis B today.

There are conditions that dinosaurs had when they died that were not necessarily the cause of their demise. Several specimens had infected or missing toes, and trace fossils show animals limping. Dinosaurs even got ticks and fleas.

Finding footprints

Dinosaurs left impressions in mud that could harden into stone. We measure their dimensions, but there is more information hidden in a trace fossil. We can glean skin texture, the length of their strides and even deduce complex behaviour like building nests. Footprints left by an *Eubrontes* 200 million years ago, found in modern-day North America, were startlingly similar to modern birds. They show a sequence of a dinosaur stopping for a rest by the lake. There are footprints leading to a divot created when it squatted down, then steps leading away while the tail dragged on the ground.



Footprints left by carnivorous dinosaurs in the late Jurassic period near Tuba City, Arizona



Musculoskeletal structure of the fossilized vertebra of *Protoceratops*, the most complete of its kind discovered to date

The story of bones

Bones give us huge clues about a dinosaur's size, posture and locomotion. Scientists can reconstruct muscle and cartilage by examining marks on bones. Erosion to the teeth tells us what the animal ate. CT scans build up 3D images of bones by taking panoramic X-rays. We've found that a great deal of dinosaur bones contained air sacs like birds do. Using this technique we are able to figure out how old a dinosaur was when it died, what its skin looked like and even the size of its brain. Muscles and skin can be layered onto reconstructed skeletons in order to create accurate pictures of long-dead dinosaurs.

Signs in skulls

A dinosaur skull is a goldmine. It contained the eyes, mouth, nose, ears and brain of the animal. We have learned an incredible amount about dinosaurs by studying their skulls.

Scientists digitally recreated a *T. rex* skull and rebuilt the muscle by researching the jaws of birds and crocodiles. They found it had a bite force of about 5,800 kilograms, the hardest bite of any terrestrial animal in history. The muscles responsible for closing the jaws grew exponentially when the animal matured and were extremely large, even for such a big animal. This figure is not agreed upon by all dinosaur researchers though.



We know that *Spinosaurus* was adapted for swimming because of the position of its nostrils. They were far back on the top of the narrow skull, a lot like a crocodile's. It was probably bigger than *T. rex* judging by the length of the snout, possibly reaching 16 metres long.

Q&A

The big dino questions

We spoke to Eofauna's dinosaur experts about how they create accurate models of these extinct creatures

What can fossils tell us about a dinosaur and its appearance?

It depends heavily on the quality of fossil data. The more complete the remains are, the more accurate the dinosaur representation will be. If a skeleton is fairly complete, we can restore the shape of the animal accurately. This requires adequate knowledge of comparative anatomy for reproducing good digital reconstructions of muscles and bones. We usually use modern birds, but distantly related animals like elephants are useful for sauropods in terms of biomechanics and posture.

Did most dinosaurs have scales or feathers?

All dinosaurs had scales but some, especially the most advanced theropods, also possessed feathers. Only a few species had developed secondary feathers. Dinosaurs probably all had simple developing feathers we call filaments.

Can we be sure what colour a dinosaur was?

No. Apart from a very few cases where melanosomes have been preserved, we can only speculate. Colours can be estimated from the animal's lifestyle, size and the climate they inhabited.

What big questions do we still have about dinosaurs?

One of the trickiest issues is how to determine a dinosaur's sex. It has been the focus of many studies but has been found to be more complex than we first thought. Other mysteries include what their behaviour and cognitive abilities would have been like. Living animals are good in these aspects, but there is very little evidence in dinosaurs.

Asier Larramendi and Ruben Molina

Scientific directors at Eofauna

Asier and Rubén are the founders of Eofauna, a company that creates scientifically accurate representations of prehistoric fauna. Asier's work focuses on the comparative anatomy, body size, biomechanics and functional morphology (shape) of extinct vertebrates. Rubén specialises in biogeography, biometrics, ichnology (footprints) and bibliographic documentation.



settle the matter. After a long debate, Anning's plesiosaur was confirmed to be legitimate. However, it wasn't a bad idea to take discoveries with a pinch of salt because forgers had already begun to scam museums with fake fossils.

The dawn of palaeontology was an exciting time, but many researchers thought it was too early to be drawing conclusions from such a small record. Others documented all the information they could, but it involved a lot of paperwork. Everything had to be written down, from fossil databases and family trees to painstaking statistical analysis. German palaeontologist Heinrich Georg Bronn was at the forefront of logging dinosaur data. He used innovative methods to represent information that was new at the time, like graphs. He built up a database by studying what fossils looked like and crunching the numbers. The index he published in 1849 demonstrated when certain species appeared and disappeared at different times and was a remarkable breakthrough.

Radioactivity was discovered in 1896, and it wasn't long until it could be used to measure geological time by studying the rate of decay of naturally occurring radioactive isotopes. This helped determine the age of fossil rocks, and by the end of the century scientists had worked out a rough timeline of when these creatures lived. They began to realise the planet was much older

"Forgers had already begun to scam museums with fake fossils"

than they had previously thought and started to see geological history very differently.

The invention of computers had a big impact on data analysis, as a lot of information could suddenly be processed by a machine in a short time. Computers transformed the entire discipline of palaeontology. Huge databases have been built online, and computers are able to model the relationship between fossils and life on Earth now. Perhaps most importantly, we can build up images of what dinosaurs looked like using precise imaging techniques. There's a lot we still don't know, but we're making new discoveries all the time.

Learn more

The *Encyclopedia Of Dinosaurs: The Theropods* is written by Eofauna researchers Rubén Molina and Asier Larramendi and illustrated by Andrey Atuchin and Sante Mazzei. More information at www.eofauna.com.

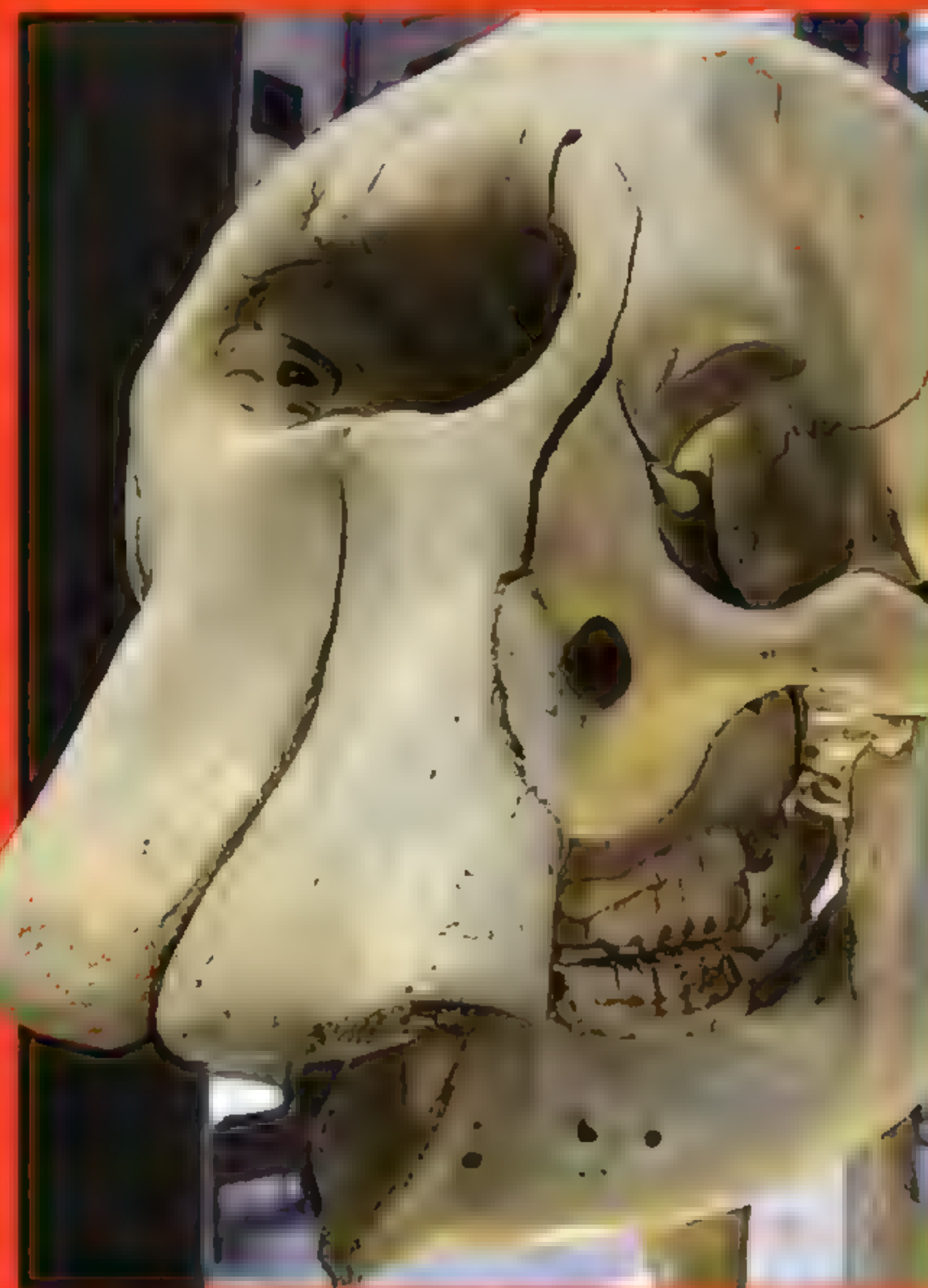


Dinosaur myths and legends

Remains of large, extinct animals have been found throughout history, long before we knew what they were. The enormous bones inspired people to speculate about what bizarre creatures might exist in the vast world around them.

Circular holes in skulls of extinct elephants might have convinced ancient Greeks of the existence of the one-eyed cyclops. It's been suggested that griffins, sphinxes and sea monsters had their origins in fossil remains too.

There's a good chance dinosaur remains also sparked myths about dragons. It would explain why they are part of mythology in so many cultures across the globe and have been for a very long time. Sculptures of dragons in China date back to around 6000 BCE. They were constructed by Neolithic humans and were probably worshipped. Chinese historian Chang Qu wrote about dragon bones in around 300 BCE, but we don't know what animal they really came from.



The eye socket of a mammoth skull is usually where a single tusk would be located.

A worker lies down next to the humerus of a Brachiosaurus, South America, circa 1890.



200 years of dinosaur development

Our understanding of the Iguanodon has changed dramatically over the centuries

1822

The first Iguanodon teeth are found by Mary Ann Mantell and studied by her husband Dr Gideon Mantell. Georges Cuvier states his belief that they may have been from an extinct hippo-like animal.

1825

The fossilised teeth resemble those of an iguana, only many times larger. Mantell names the creature Iguanodon, which means 'iguana tooth'.

1853

Sir Richard Owen and his associate Benjamin Hawkins reconstruct Iguanodon. They put its spiked thumb on the tip of its nose, believing it to be a horn, with the dinosaur standing on all fours.

1872

The spike is recognised as one of a pair of sharpened digits that protrude from the wrists. They are believed to have been used as weapons that served no other purpose.

1882

Dr Louis Dollo rebuilds an Iguanodon skeleton, modelling it on the modern emu. The new reproduction stands erect on two legs.

1980

Dr David Norman analyses the dinosaur's tail and realises it wasn't flexible, and therefore Iguanodon must have walked on all fours. He also notices its fingers were able to grasp objects.

2005

After studying their footprints we now think Iguanodon was an optional tetrapod able to balance on its back legs. Trace fossils indicate it was around ten metres long.



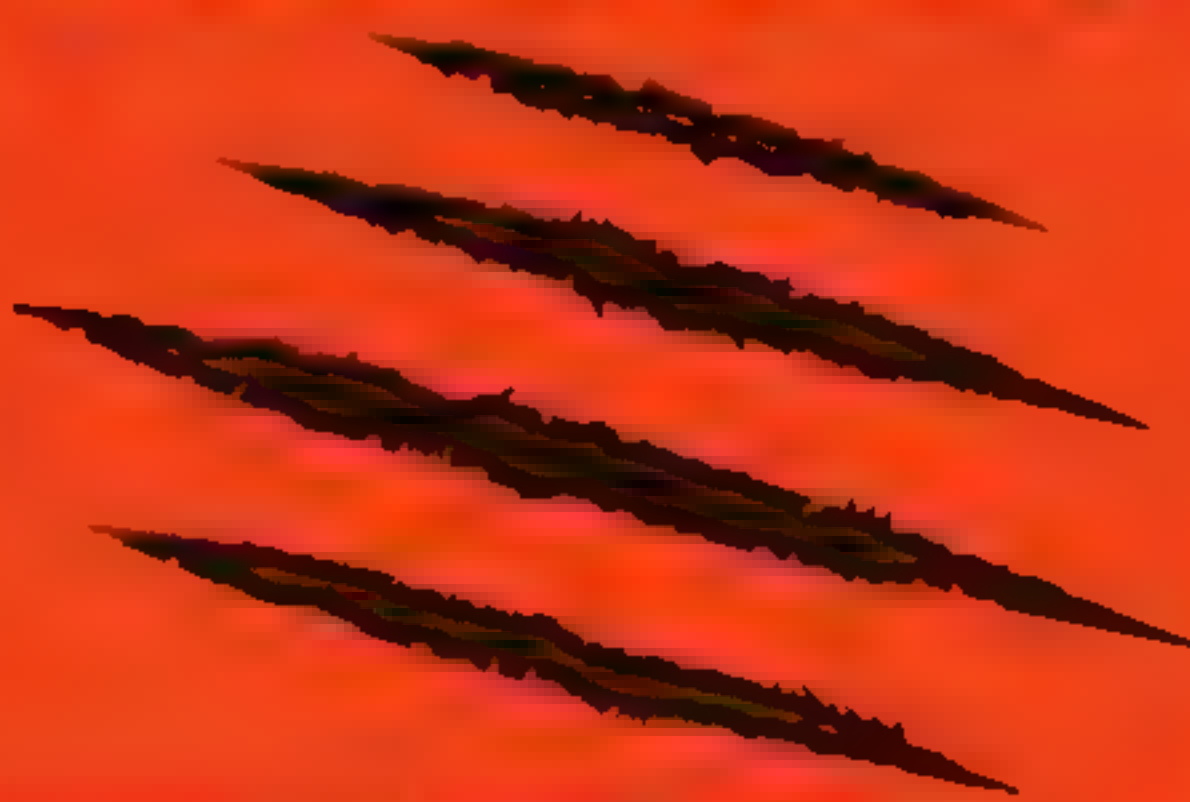
An Apatosaurus skeleton that was misidentified in 1877 and was corrected in 1903

15



A T. rex had 60 serrated teeth that could be up to 20cm long

75 cm



THE OLDEST FOSSIL POO IS MORE THAN 200 MILLION YEARS OLD



HERBIVOROUS DINOSAURS ATE ROCKS TO HELP GRIND UP SWALLOWED FOOD

1 METRE

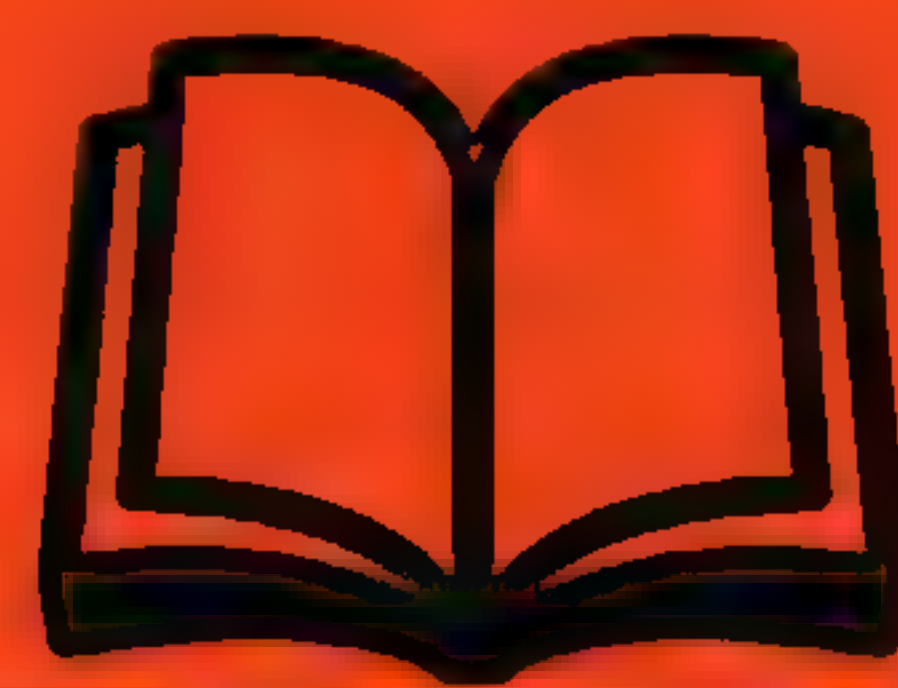


WE DON'T KNOW WHY STEGOSAURUS HAD PLATES ALONG ITS BACK ?



30 YEARS

700



Some think Apatosaurus could break the sound barrier by whipping its tail



1cm



Champion sprinters

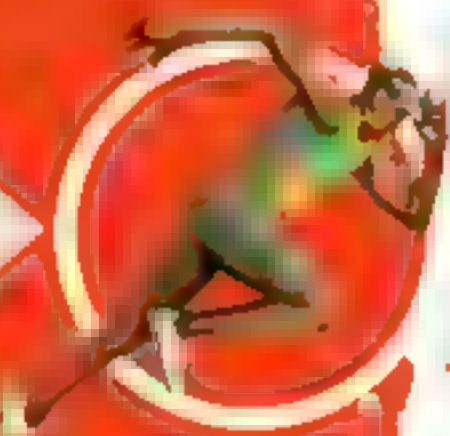
Extinct theropods were seriously quick and a match for fast runners that live today

We estimate a dinosaur's speed by considering a number of factors. We look at the length of its strides, how many steps it took per second and the proportions of its leg bones. All of this data is compared to that of modern running birds like ostriches, yielding results that seem logical. The animal's mass also had a significant effect on how fast it could run. T. rex was only as fast as the extant roadrunner because it was so heavy.

An animal well adapted for running is described as cursorial. Estimated values of cursoriality come from body mass, cadence and stride ratio. These numbers are multiplied by the length of the dinosaur's legs to calculate the speed it was capable of reaching.

44.72 kph

Usain Bolt



105 kph

Diamondback



72 kph

Greyhound



68 kph

Cheetah



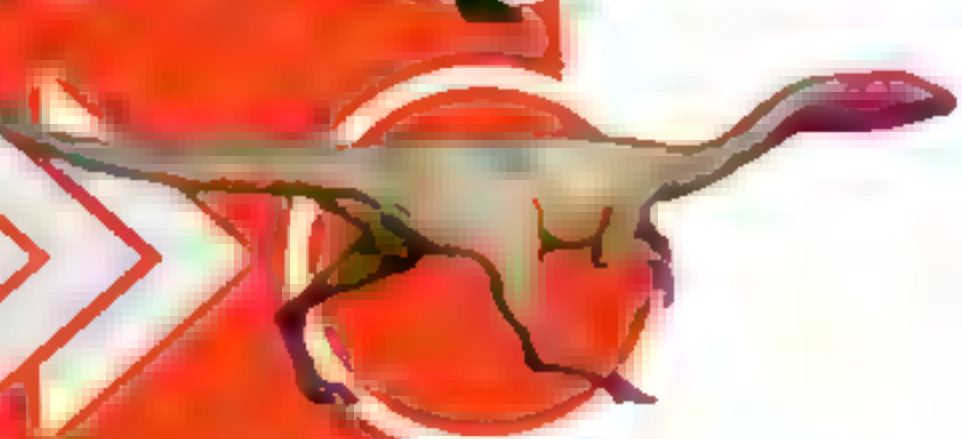
42 kph

Wolverine



41 kph

American alligator



28 kph

American bison



23 kph

American pronghorn



20 kph

American bison



Inside Atlasaurus

It was new to science in 1999 – now we have the technology to get under the skin of this giant herbivore

Skull

Evidence suggests that Atlasaurus had a larger cranial cavity than the closely related Turiasaurus and probably had a bigger brain.

Herbivorous teeth

Atlasaurus had teeth designed to shear through tall vegetation.

Squat neck

Skeletal remains tell us it had at least 13 vertebrae in the neck. They were relatively short and all roughly the same length.

Strong shoulders

The front limbs were arms rather than legs, and the muscles at the base of the neck were fairly similar to those in human shoulders.

Claws

Sauropods like Atlasaurus used their claws to excavate nests. Examinations of footprints revealed they weren't used to grip the ground.

Mystery muscles

We don't know if these dinosaurs needed warmth from the Sun or generated their own heat, so it's hard to estimate how much muscle they would have had.



© EOLAJNA



The *Sinosauropteryx prima* was the first dinosaur to be found with feathers

Why were the dinosaurs so big?

The niches left by the victims of the Permian extinction 250 million years ago were soon occupied by newly evolved dinosaur species. Dinosaurs could eat fibrous plant matter without chewing it. They could consume a lot in a short time and eventually grew to be enormous. Big dinosaurs also had few predators, so size was selected for by nature.

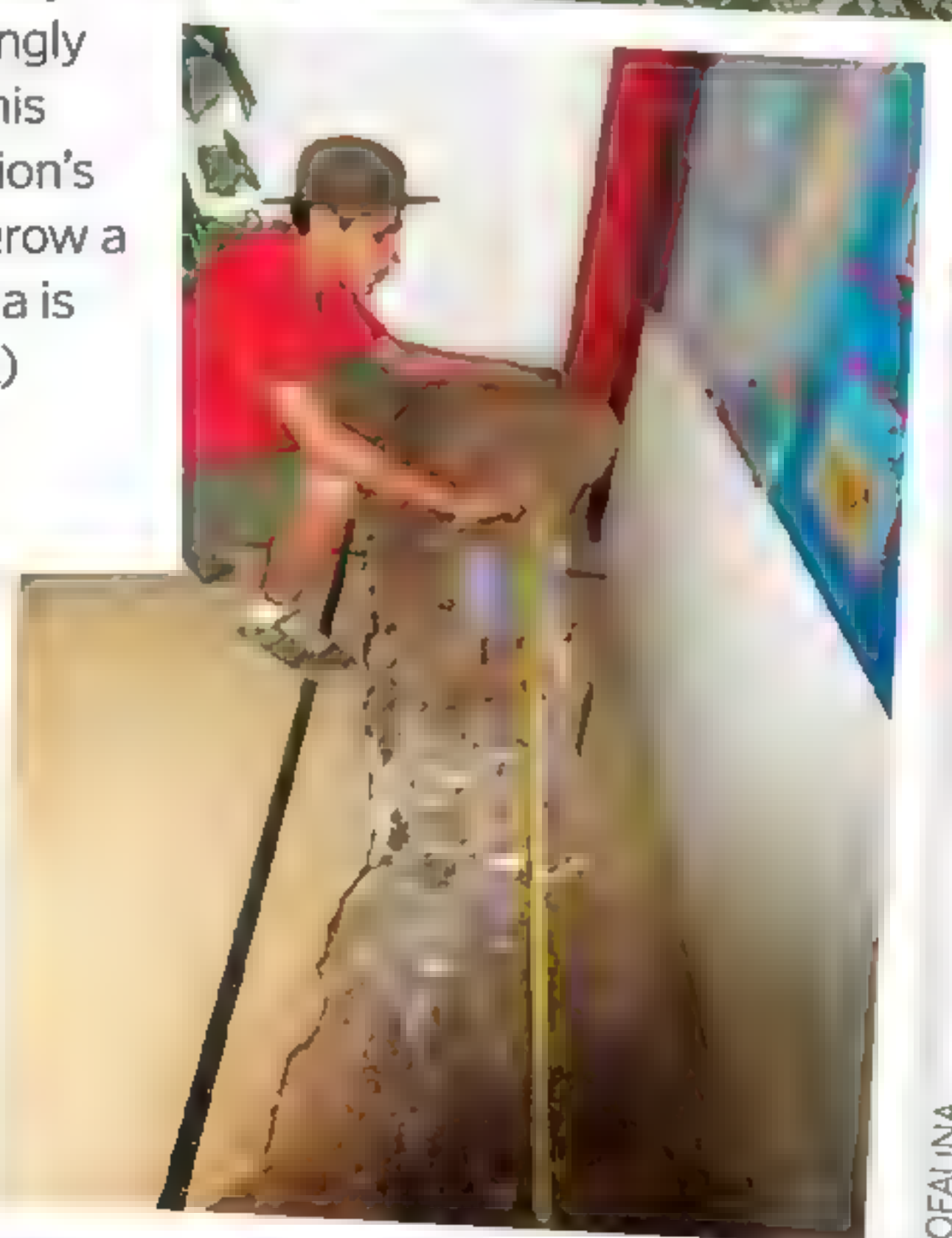
Reptiles could grow much larger than mammals because of their thicker limb bones and huge cartilages. These shock absorbers reduced stress on the joints, which allowed them to achieve body masses many times that of most large mammals.

Long tail

This dinosaur could have been able to whip its tail in self-defence, but we're still not sure about that.

Long legs

Atlasaurus was essentially on stilts, with limbs seemingly too long for its body. This could have been evolution's way around having to grow a long neck. Rubén Molina is seen in the photo (right) measuring a massive sauropod femur.



© EOFAUNA

Even though pterosaurs could fly, birds evolved from two-legged carnivorous dinosaurs



EOFAUNA

Bringing extinct animals to life

EOfauna's Asier Larramendi tells us how scientifically accurate prehistoric beasts are reconstructed in 3D

"We first either visit museum collections to take photos and measurements or take information about the best-preserved specimens already published in scientific papers. Once we have the proper documentation, we produce a detailed skeletal reconstruction diagram first to have a precise idea of the proportions of the living animal. It is very important to have a well-rounded understanding of how skeletal elements interconnect, a good knowledge on the muscular system of similar living animals today and how other soft tissues (skin, hair, scales, feathers, etc.) are placed in living organisms. This is what is called comparative anatomy.

From this we create a 3D skeleton. In order to make sure its morphology (size and shape) is accurate, we use a photogrammetry technique: we take a series of

photographs of the bones from different angles, then digitally generate a 3D model by comparing characteristics in the images. Once the 3D skeleton model is finished by our sculptor Shu-yu Hsu, we add musculature by comparing the extinct species with modern relatives.

For example, if we are working with an extinct proboscidean (elephants and their relatives), the muscle system of modern elephants can be applied (as per *Palaeoloxodon antiquus* above). If we are working on a dinosaur, we use living archosaurs (crocodiles and birds).

After this the skin and coverings are added. Sometimes we have very good information on extinct animals' skin and covering, such as hair, scales, filaments or feathers. A great example is the woolly mammoth - some superb frozen specimens have been found. Despite dinosaurs going extinct 66 million years ago, some exceptional specimens have also been found (with soft tissue). These are useful to create a better representation of the living dinosaurs. Finally, we give dynamic poses (running, walking, etc.) based on skeletal motion ranges and biomechanics."



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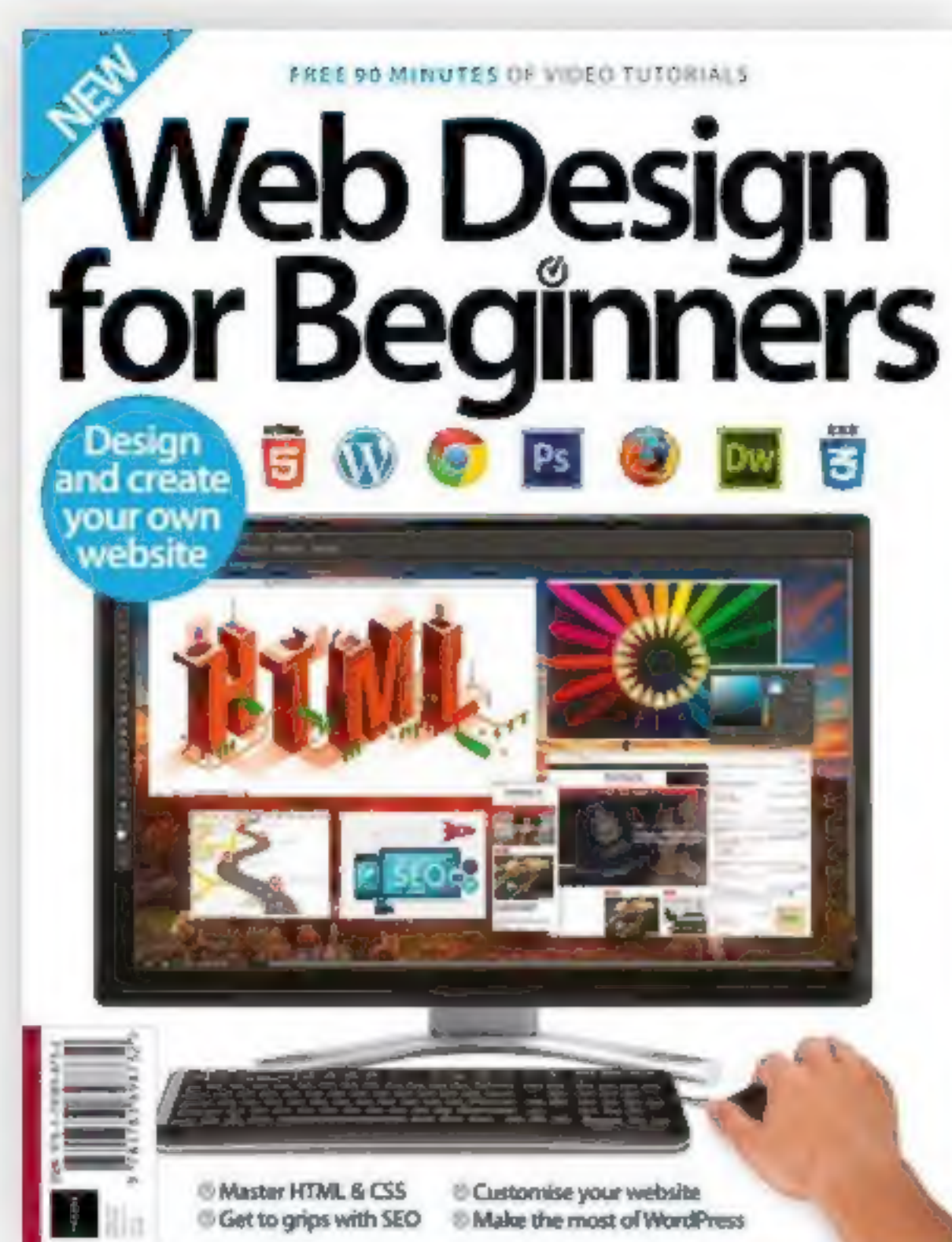


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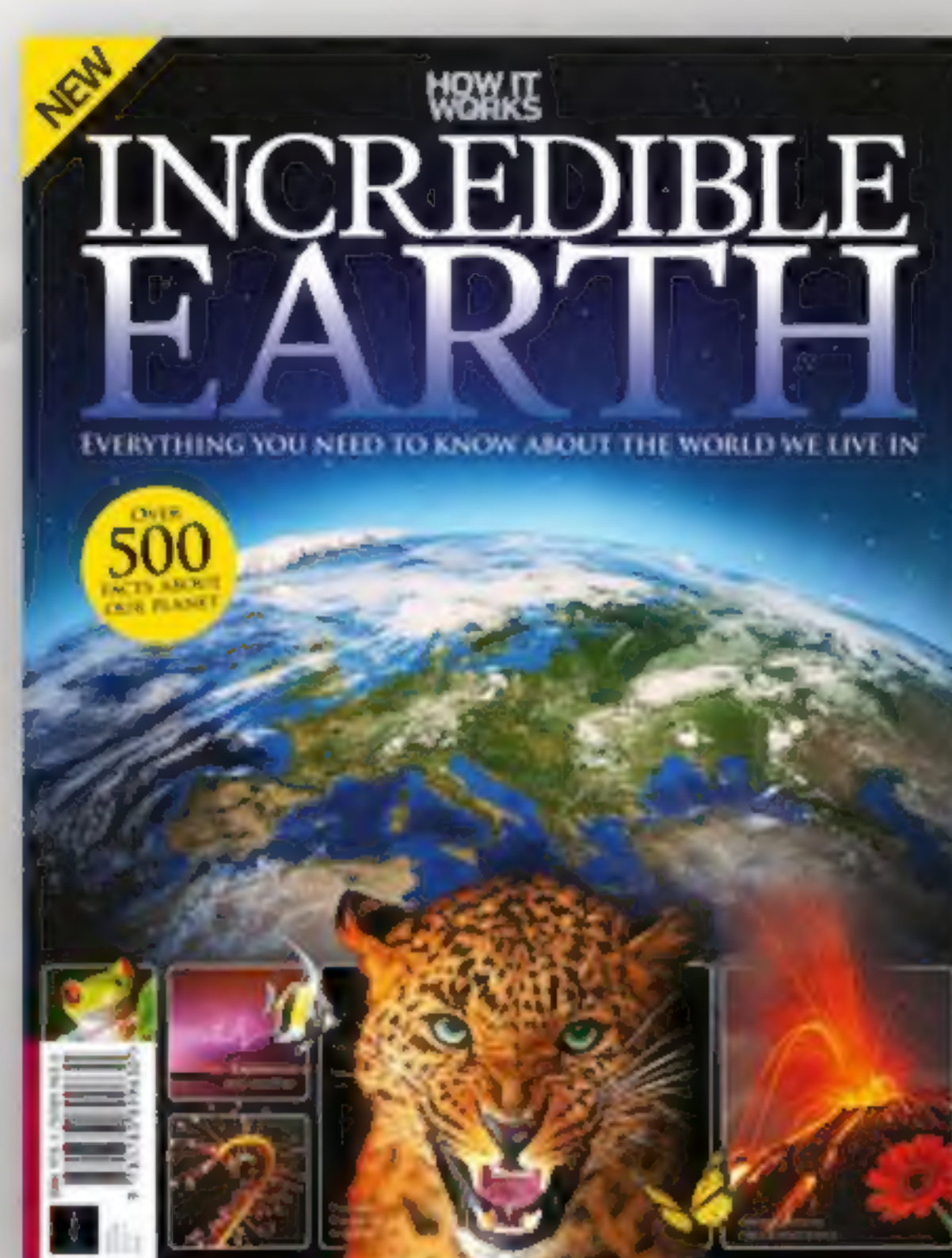


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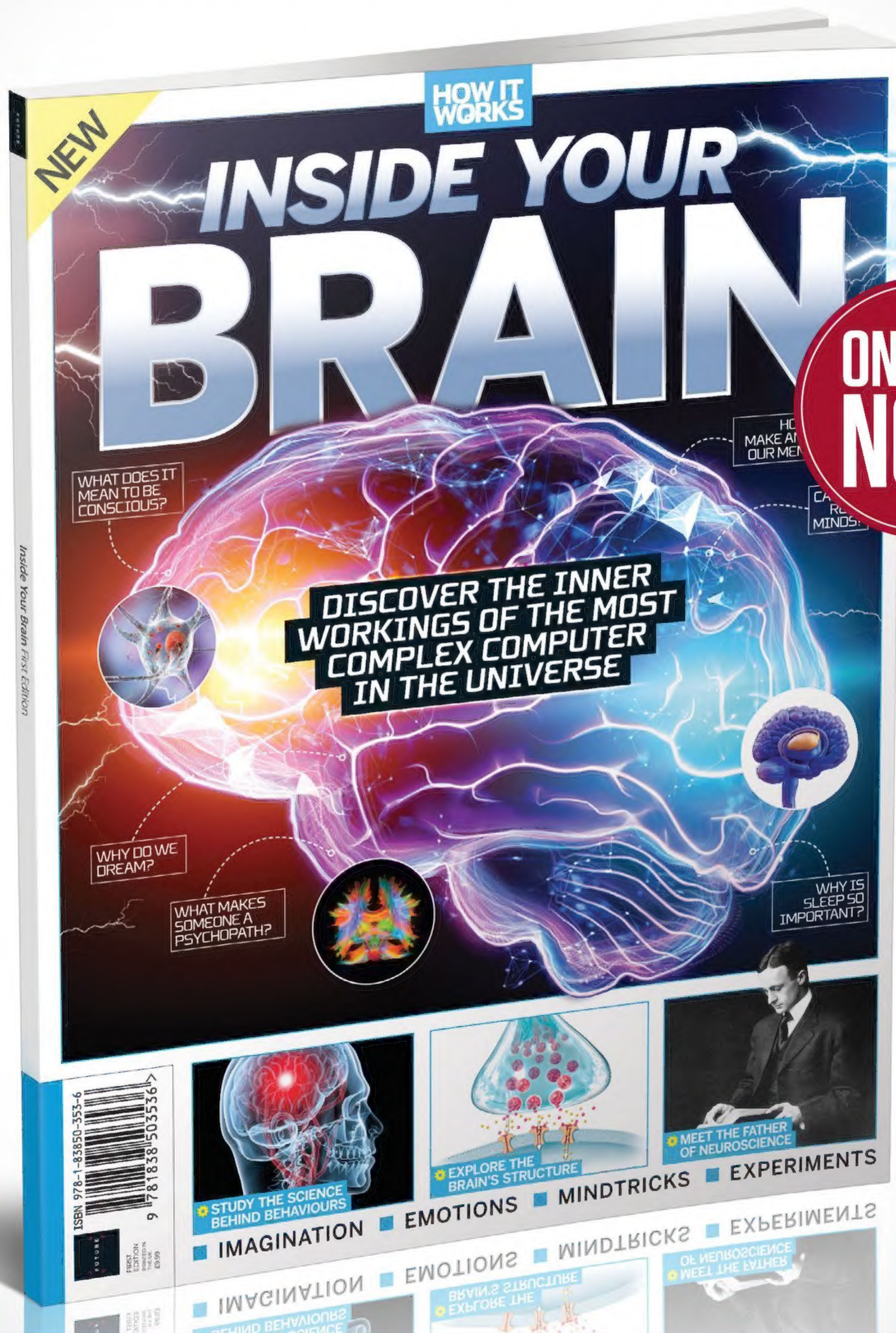
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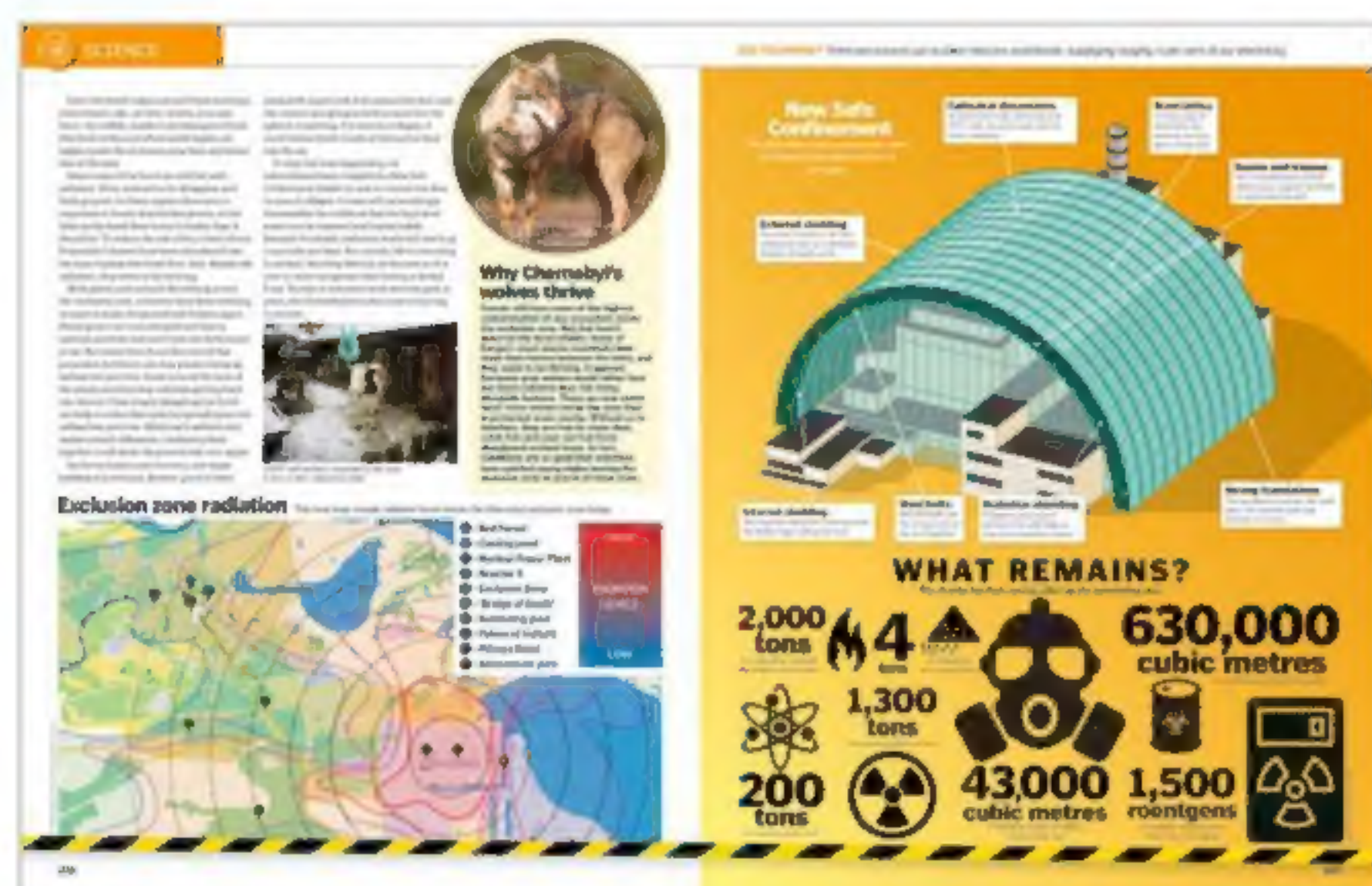
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TRANSPORT

Take to the skies in a Hawk T1 jet, examine the machines set to take over the front lines and find out how cement mixers work



ENVIRONMENT

From hyper-venomous snakes to coma-inducing flora, this annual's environment section is not for the faint-hearted!



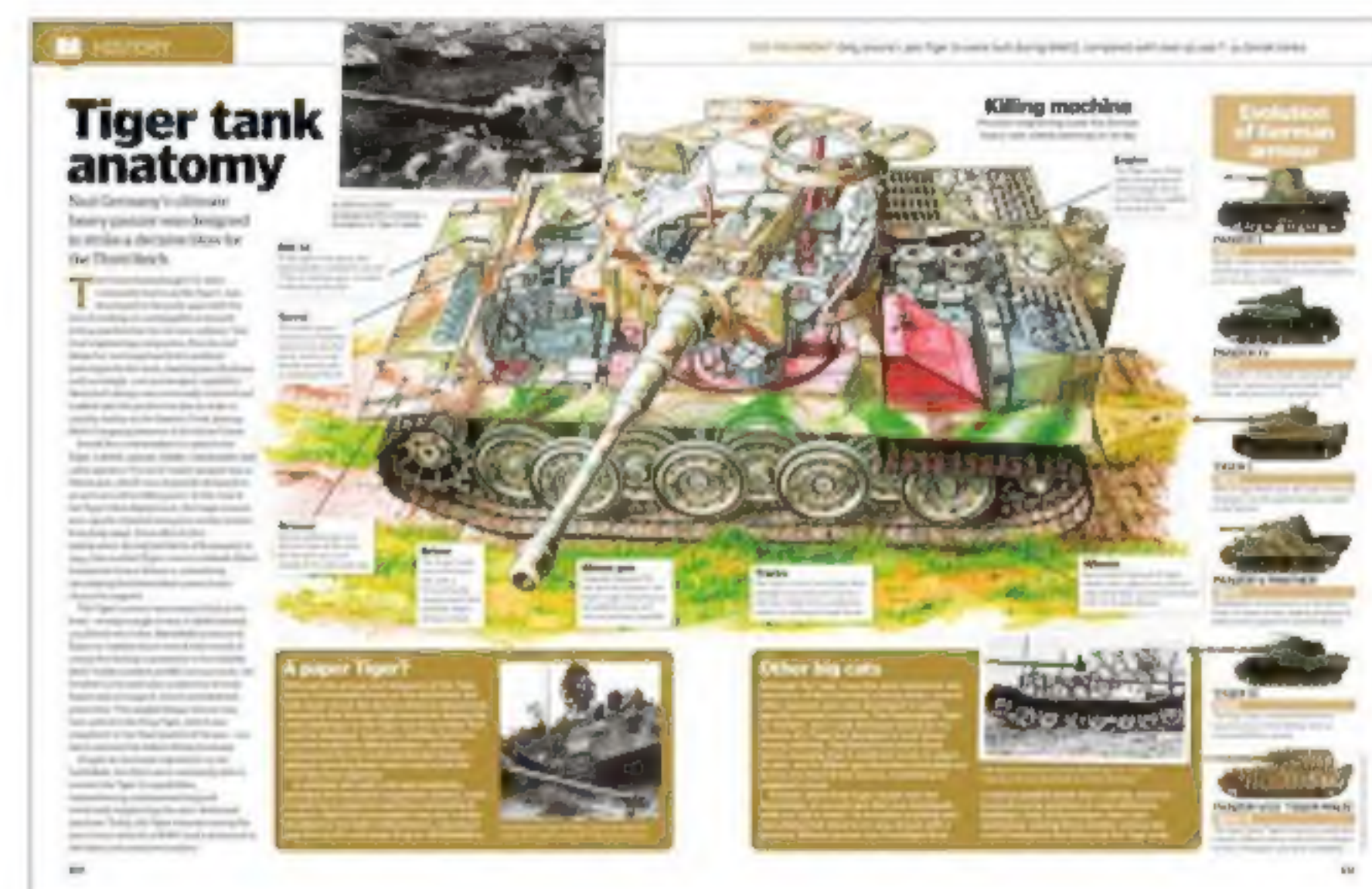
TECHNOLOGY

Tour the new super sewer being excavated under London, learn how movie magic is made and meet the man behind the mobile



SPACE

Explore the mission to delve into Mars, uncover the secrets of Apollo 11 and discover what happens when two galaxies collide



HISTORY

Get under the shell of a Tiger tank, dig up the frozen fossils of the past and get to grips with some of da Vinci's most ingenious inventions

